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THE SOCIETY OF AUTOMOTIVE ENGINEERS

INC.

1917

TRANSACTIONS

PART I

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THE SOCIETY OF AUTOMOTIVE ENGINEERS

1917 TRANSACTIONS

PART I

VOLUME XII

Comprising Papers and Reports and Discussion of Same Presented at the January, 1917, Meeting of the Society, and some Papers Presented at Meetings of Sections of the Society.

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OFFICE OF THE SOCIETY
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The
Society of Automotive Engineers

Founded 1905 — Incorporated 1909

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The Society shall not be responsible for statements or opinions advanced in papers or discussions at its meetings * * *
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CONTENTS*

PAGE

Aeronautic Engine Division, First Report 1
Electrical Equipment Division, Eighth Report 7
Electric Vehicle Division, Fifth Report 8
Engine and Transmission Division, First Report 9
Iron and Steel Division, Tenth Report 17
Miscellaneous Division, Ninth Report 17
Springs Division, Sixth Report 18
Tire and Rim Division, First Report 20
Truck Standards Division, First Report 25
Presidential Address 28
Constitutional Amendments, Discussion 30
Applications Approved by the Council 36
Election of Officers 36
Council Meeting Attendance 37
Treasurer's Report 38
Some Problems in Airplane Construction
V. E. Clark, T. F. Dodd, O. E. Strahlmann 40
The Ultimate Type of Tractor Engine
H. L. Horning 65
Heat-Balance Tests of Automobile Engines
W. F. Fishleigh and W. E. Lay 82
Some Essential Features of High-Speed Engines
A. F. Milbrath 104
Dynamic Balancing of Rotating Parts
F. Hymans 113
Remarks on Dynamics of the Automobile
N. W. Akimoff 141
Aerial Navigation Over Water
E. A. Sperry 153
Standardization of Metal Parts for Aeronautical Use
F. G. Diffen 166
Some Notes on High-Pressure Aviation Engines
L. M. Griffith 180
Suggestions for Standard Tests of Airplanes
Jno. J. Rooney 194
Evolution of Airplane Wing-Trussing
F. W. Pawlowski 207
Steam Motor-Vehicles
Abner Doble 220
The Gap Between Commercial Men and Engineers
C. W. Mears 232

*General Index to subjects on page 433.

Digitized by Google

(**Contents Continued**)

PAGE

PROGRESS OF THE YEAR AS OBSERVED AT AUTOMOBILE SHOWS
J. Edward Schipper 239
METHODS OF COMPARING AUTOMOBILE PERFORMANCE
W. T. Fishleigh 258
CHASSIS LUBRICATION
Roland Chilton 280
HEAD-LAMP GLARE—WHAT IS IT?
J. B. Replogle 297
A STANDARD OF CARBURETER PERFORMANCE
O. C. Berry 312
OVERHEAD VALVE PROBLEM OF AN ALUMINUM ENGINE
A. L. Nelson 328
TESTING VARIABLE-SPEED ENGINES BY A NEW METHOD
Daniel Roesch 338
THE FUEL QUESTION—FROM THE DRIVER'S VIEWPOINT
F. C. Mock 347
RETARDATION OF THE AUTOMOBILE
John Younger 365
POWER LOSSES IN PNEUMATIC TIRES
E. H. Lockwood 377
HEAD-LAMP DESIGN AND ITS EFFECT UPON GLARE REDUCTION
A. L. McMurtry 387

Digitized by Google

Contributors and Speakers

PAGE

W. D. Apple 230, 231
N. W. Akimoff 139, 141*, 172
B. B. Bachman 23, 370, 383, 384
W. C. Baker 228, 229
P. F. Bauder 7
David Beecroft 359
Louis Bell 304
O. C. Berry 312*, 320, 322
S. L. Blackburn 228, 230, 231
W. R. Blair 206
G. A. Breeze 291
R. M. Brown 174
A. B. Browne 99
A. K. Brumbaugh 382, 385, 386
A. P. Brush 178, 270, 277, 320, 321, 324, 326, 327
Wm. H. Burton 357
F. W. Caldwell 63, 308
Leon Cammen 371
C. C. Carlton 22
J. R. Cautley 205
Herbert Chase 150, 360
Henri G. Chatain 80
R. C. Chestnut 111
Rowland Chilton 280*
Wm. Churchill 418
E. L. Clark 230
Capt. V. E. Clark 40*
A. L. Clayden 5, 8, 27, 171, 191, 369, 374
H. E. Coffin 33
R. H. Combs 31, 33
W. H. Conant 32, 34, 310
LeRoy V. Cram 336, 337
R. H. Cunningham 189, 190
D. P. Davies 79
A. M. Dean 230
H. C. Dickinson 190, 359, 364
F. G. Diffin 166*, 170, 179
Abner Doble 220*, 227, 228, 229, 230, 231
Capt. T. F. Dodd 40*
G. H. Engelhard 34, 35
E. H. Erhman 7, 173
J. W. Esterline 321
Walter T. Fishleigh 16, 82*, 258*, 279

Digitized by Google

Contributors and Speakers (Continued)

PAGE

F. H. Floyd 286, 292
H. P. Gage 415
Fred C. Glover 362
L. E. Goodier 177
B. D. Gray 384
G. A. Green 24, 34
L. M. Griffith 6, 80*, 193
C. P. Grimes 326
J. E. Hale 21, 23
H. W. Harms 203
V. R. Heftler 273, 322, 326
C. C. Hinkley 252, 273, 275, 276
M. C. Horine 21
H. L. Horning 65*, 73, 80, 98, 360, 363
W. S. Howard 6
Russel Huff 30, 31, 32, 33, 34
O. E. Hunt 275, 290
J. H. Hunt 190
Howard Huntington 203
F. R. Hutton 32, 33, 34, 411
F. Hymans 113*, 137
Robert Jardine 177
C. F. Jeffries 255
Ferdinand Jehle 98, 203, 206
R. B. Jones 202
G. W. Keen 290
W. E. Lay 82*
E. H. Lockwood 100, 377*, 382, 383, 384, 385, 386
W. F. Little 413
C. M. Manly 5, 175, 188, 192, 203, 205, 218
H. P. Maxim 191
W. E. McKechnie 418
A. L. McMurtry 387*
C. W. Mears 232*
A. F. Milbrath 104*
F. C. Mock 327, 347*
F. L. Morse 4
F. E. Moskovics 322, 337
Cornelius T. Myers 254, 269, 272, 277, 288, 292
A. L. Nelson 328*, 336, 337
W. M. Newkirk 371
H. H. Newsom 228, 229, 230
L. G. Nilson 178
F. W. Pawlowski 207*
F. E. Place 362
E. Planche 187, 274
R. E. Plimpton 385, 386

Digitized by Google

Contributors and Speakers (Continued)

PAGE

FREDERICK PURDY 323, 326, 361
J. B. REPLOGLE 176, 272, 276, 297*
A. L. RIKER 21, 24, 26, 35
J. C. RILEY 204, 205
E. V. RIPPINGILLE 278
DANIEL ROESCH 328
JNO. J. ROONEY 194*
DELMAR ROOS 137
A. J. SCAIFE 227, 229, 231
J. EDWARD SCHIPPER 239*, 256, 286
H. W. SLAUSON 411
S. E. SLOCUM 149
G. W. SMITH 231, 362
M. A. SMITH 81
E. A. SPERRY 153*, 177, 205
HENRY SOUTHER 175, 176, 202, 205
A. L. STEVENS 255
W. B. STOUT 191, 278
O. E. STRAHLMANN 40*, 218
C. H. TAYLOR 179
E. G. THOMAS 227
W. F. THOMAS 173
M. TOMLINSON 289
J. G. VINCENT 2, 4, 178, 188, 191
E. F. WACKWITZ 306
WM. G. WALL 336
C. R. WATSON 276
J. W. WATSON 385
W. W. WELLS 99
D. MCCALL WHITE 285
E. R. WHITNEY 374
C. B. WHITTELSEY 22
C. E. WILSON 231
A. C. WOODBURY 178
JOHN YOUNGER 22, 365*
K. W. ZIMMERSCHIED 4, 5, 8, 21, 22, 24, 34, 269, 289

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ANNUAL MEETING OF THE SOCIETY OF AUTOMOTIVE ENGINEERS

Held at
Engineering Societies Building
New York

January 10 and 11, 1917

MEETING OF THE STANDARDS COMMITTEE

The Standards Committee meeting was called to order at 10.25 a. m., Jan. 10, by Chairman A. Ludlow Clayden.

FIRST REPORT OF AERONAUTIC ENGINE DIVISION

(*As Adopted by the Society*)

1—The Division recommends a tapered shaft-end for mounting propeller hubs, for adoption as standard practice with aeronautic engines.

2—At the October meeting of the Standards Committee the Division recommended a tapered shaft-end for mounting propeller hubs, but this proposal was not voted on. Since that time additional reports have been received from France and from New Mexico to the effect that the tapered and keyed fitting for propeller hubs is giving entire satisfaction.

3—The Division therefore submits for adoption as *recommended practice* practically the same dimensions as were submitted at the

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October meeting, the only difference being that the proportion of the tapered length to be relieved has been reduced somewhat. The proposed dimensions are shown in Fig. 1.

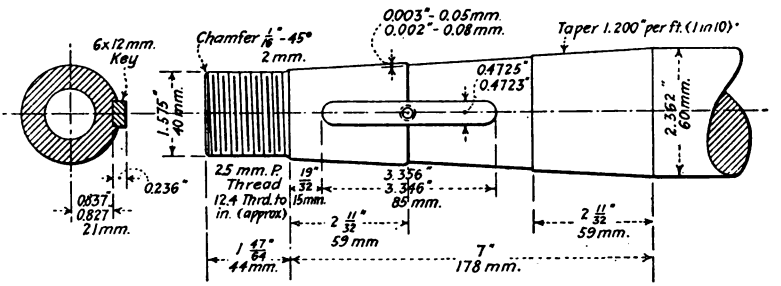

FIG. 1—SHAFT-END FOR MOUNTING PROPELLER HUBS

Direction of Engine Rotation

4—At the October meeting of the Standards Committee the Division reported definitions of terms for direction of engine rotation. Because of lack of agreement with the National Advisory Committee, the Council of the Society referred the definitions back to the Division. The Division has accordingly prepared new definitions, making use of the terms "normal" and "anti-normal" in place of the terms which have formerly been used and have caused confusion because they have not been used uniformly. These new definitions are to be submitted to the National Advisory Board in order to secure agreement if possible before submitting them to the Society for adoption. Respectfully submitted.

AERONAUTIC ENGINE DIVISION,
HENRY SOUTHER, *Chairman.*

DISCUSSION AT STANDARDS COMMITTEE MEETING

J. G. VINCENT:—One thing that came up for considerable discussion by the members of the Division is the method of expressing proposed standards. For instance, the consensus of opinion is that we want to use what has been known as the metric spark-plug, but there has never been any standard so far as the length of the metric spark-plug is concerned. After considerable discussion we agreed on some of the dimensions, but of course we could not change the diameter or the pitch of the thread. We have however put a limit on the threads of 18 mm., which is equal to the diameter of about 11/16 in.

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The next thing discussed was the over-all height, so we might know how much room we had to provide to get in the spark-plug. We have specified 70 mm. as the total maximum height from the thread to the top of the spark-plug. The average height seems to be around 60 to 65 mm.

We settled on 1 in. for the short diameter of the hex; this should be 25 millimeters. There was a discussion whether it should be 25 or 26 mm. but as I remember, we decided on 25 mm. as being almost the same as an inch. Then we put on a minimum dimension for the round part above the gasket seat, which is 1 in. diameter and should not be less than 10 mm. long, on account of the necessity of it fitting into the counterbore; we made the hex the same length, a minimum of 10 mm. or ⅜ in.

The Division wants advice as to whether the things taken from the countries using the metric system should have the metric dimensions, or whether we should give the ordinary English dimensions only, or put both on. It is an open question. For instance, in the case of the present spark-plug we decided to keep our present standard diameter, but some one suggested that so long as we do that we might just as well make all the rest of the dimensions the same as ordinary every-day standards, and simply give the decimal equivalent in inches for the metric pitch.

There was considerable discussion as to whether we could settle on engine support dimensions for particular sizes, it being thought that the 12-in. dimension was suitable for engines of 100 hp. or under, the 14-in. from 100 to 200 hp. and the 16-in. for 200 hp. or more. There seems to be no real reason for assigning them to any particular horsepower; the reason for selecting the three dimensions is that almost any engine built today can be put into one of those beds without change.

At the October meeting of the Standards Committee the Division proposed for acceptance a tapered shaft-end for mounting propeller hubs, but this proposal was not voted upon. Since that time additional reports have been received from France and from New Mexico to the effect that the tapered and keyed fitting for propeller hubs is giving entire satisfaction. The Division therefore submits for adoption as recommended practice practically the same dimensions as were submitted at the October meeting, the only difference being that the portion of the tapered length to be relieved has been reduced somewhat.

The Division is not prepared yet to recommend dimensions for hub flanges, but the Aviation Section of the Signal Corps will submit drawings suggesting different sizes of hubs.

We have investigated different mountings carefully, and if we are going to adopt anything at the present time this design proposed is the only thing we can consider, because it is the only thing suggested that has any experience behind it whatever. We have not found any-

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one that has a legitimate criticism of the design. This particular size is known to be satisfactory so far as strength is concerned for engines of 250 hp., and it is used in Europe, as we understand it, for engines of 100 hp. or less. So that at present we do not see any reason for recommending any more than one size. If a smaller size or still larger size is required we will gradually work into it. The adoption of the one size will get us to working along the same lines and allow us to build engines on which propeller hubs will be interchangeable.

The Division has prepared new definitions for direction of engine rotation, making use of the terms "normal" and "anti-normal" in place of the terms that had caused confusion because they have not been used uniformly. These new definitions are not to be reported to the Society at the present time, but are to be submitted to the National Advisory Committee for Aeronautics in order to secure agreement if possible before further definite action is taken.

The definitions prepared make use of the terms "normal" and "anti-normal". If the propeller is turning anti-clockwise, as viewed from the front or power take-off end of the shaft, its rotation will be normal; in other words, it will be just the same as looking at the rear or power take-off end of the crankshaft of an automobile engine. The power-output shaft will have the normal direction of rotation, and will take a right-hand propeller, in the case of the tractor and a left-hand propeller in the case of the pusher. In the machine having anti-normal rotation the engine will be running in the opposite direction, taking the left-hand propeller for the tractor and the right-hand for the pusher.

K. W. ZIMMERSCHIED:—I think it is desirable that the drawings be dimensioned both in the metric and the inch systems, because it is quite conceivable that some of the workmen in airplane-engine plants will have metric calipers. If we have both dimensions on the drawings it would be easy to use such instruments; on the other hand, many of them will not have such calipers, and therefore it will be advisable to have inch dimensions. I think it will help in the dimensioning of metric standards by doing so. I do not think it will cut up the drawings too much.

F. L. MORSE:—I take it that the taper shown on the shaft-end is for the crankshaft of the engine itself, or for the layshaft from the back gear. In the gear-drive machine the engine would probably be running at a much higher speed. If the shaft is made to standard size on the outside, its weight could be decreased for a less powerful engine by drilling it from the back side, but this might not be true if the shaft-end were used directly on the crankshaft. Of course weight is an undesirable feature in anything connected with a flying machine. If a single size is decided upon, it would be necessary to arrange it so it could be drilled out for lightness. Would it not be well then to take into consideration the size of the hole that might be used?

J. G. VINCENT:—It is the general practice to drill out shaft-ends; from what little I have learned that practice will vary some according

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to the part drilled. As a matter of fact, the propeller sizes are of more importance on account of the actual twisting moment of the shaft. The chances are that with the direct-drive engine the shaft will be stressed just as much as with the gear-drive job, particularly if the former happens to be a big engine. I have seen a number of engines, varying from 100 to 250 hp., equipped with this taper. We have also, peculiarly enough, designed this end for 225 hp. ourselves and arrived at just about the same size, before we knew anything about this taper. So we feel positive that it will be satisfactory for anything up to 225 hp. Of course it is possible to attach it directly to the crankshaft by drilling from the back side.

CHAIRMAN CLAYDEN:—It might be well for the committee to pass on the matter of stating metric and English dimensions.

K. W. ZIMMERSCHIED:—The discretion as to whether the metric dimensions should be given might be left with the data sheet editors, where it appears that the standards overlap European practice. The metric dimensions would not be necessary for the standards used on this side only. I move that the metric equivalent be printed with the inch dimensions with those standards that follow or run current with the European standards, in the discretion of the data sheet editors, or by advice of the Division from which the standard emanates. (The motion was seconded and carried.)

(On motion, duly seconded, it was voted that the report of the Aeronautic Engine Division be approved for submission to the Society for adoption.)

DISCUSSION AT SOCIETY MEETING

PROPOSED SHAFT-END STANDARD

C. M. MANLY:—We ought not to adopt the shaft-end standard without realizing that an early change may be required. We are now learning more about designing propellers and engine shafts than has ever been learned before. In the early engines, with the smaller horsepowers, there was no difficulty in fastening the propeller; but with engines of larger horsepowers the fastening commenced to give some trouble. We ought to get a great deal more data than we have now on the larger engines as to the effect of the local stresses set up by the keys. We cut into the shaft very brutally, especially when we consider the fact that it is a hollow shaft and made of high-grade material.

It is a question as to whether the propeller hub can be properly fitted on the shaft without actually lapping each hub to the shaft itself. The French makers do not attempt it. They make a fairly

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good fit and then they put a little emery with oil on the inside of the hub and slip it on, leaving the key out, and rub it down until they get a pretty fair bearing; then they clean it off, insert the key and put the hub on. If the fit is not good it will blister, just as many other forms of fastening will blister. Any one who has not had experience with such blistering will be surprised to see what a little bit of "out-of-trueness" or lack of completeness of fit at both ends of the key leads to in the way of blistering. For example, if the hub is fitted on the lower end of the taper and has about a quarter of a thousandth clearance at the upper end, I guarantee that it blisters in thirty minutes. In fact, it will be likely to blister to such an extent in ten minutes' running that it may be necessary to drill the hub off in order to remove it from the shaft.

W. S. HOWARD:—While I am not an airplane engineer, I really question the wisdom of reducing the shaft in the center. We had some taper shafts similar to that fail a short time ago, owing to the fact that the shaft did not fit the taper hole in the hub; the strain on the key allowed the material to stretch, making a fracture at the large end of the keyway. After this, the shaft even with the fracture went on doing the work. We replaced it with a Krupp chrome-nickel shaft, and in that case a section the width of the key and as long opened up like a hinge, showing the fracture in detail. Having some material not as good as to quality, and not having time to get anything else, we turned some shafts; all of them fractured at the large end, but continued to do the work in spite of the fracture. We then secured some nickel steel and made new shafts, machined the hubs to make a good fit over the entire length, doing the work carefully in the tool-room, and separated our keys, putting one key at the large end, running back nearly two-thirds of the length. Going around 120 deg., we placed another key the same distance from the other end. Those shafts do not show any distress or any trouble whatever and do not blister. The pressure on one key caused a slight rising, so we took the shaft out of the hub and noted which key had the greatest pressure; we eased this off slightly with a file so that both keys had the same pressure and we have been able to transmit some 175 hp. with a 1⅜-in. shaft at about 1000 r.p.m.

L. M. GRIFFITH:—The shaft-end proposed is being used largely in Europe, and it seems to be giving satisfaction there so far as we know. They are supposed to be using it on an engine of over 200 hp.

The matter of lapping on is another point. Every time they put a new hub on the shaft they do lap it on to a certain extent. The key evidently does not take a great proportion of the drive. The stress is extremely high; if we consider that the key carries the torque, the shearing stess is well up towards 100,000 lb. per sq. in., showing that the friction of the taper itself and not the key must transmit the torque.

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We should establish this shaft-end as recommended practice, so that the engineer and designer will have something to work to.

E. H. EHRMAN:—Some further action should be taken with reference to the translation of metric dimensions into decimal or inch (English) fractional dimensions, particularly with reference to the thread pitch. Any error in the pitch is about 1¾ times as serious as an equal error in the pitch diameter. It would be safer in metric threads not to state the corresponding decimal or English fractional equivalent pitches.

Many of the other equivalent dimensions do not harmonize exactly and are intended merely to be approximations, so that the metric dimensions should be so annotated as to indicate that they are approximate only, and not the exact equivalents of one another.

For instance, take the diameters of the hexagon and the cylindrical parts; if the former remained in the metric standard, and the latter were finished to the English fractional dimension, flat, narrow surfaces would show the entire length of the cylindrical portion, which, of course, is not intended.

(On motion, duly seconded, it was voted to approve the report of the Aeronautic Engine Division for submission to the Members by letter ballot.)

EIGHTH REPORT OF ELECTRICAL EQUIPMENT DIVISION

(*As Adopted by the Society*)

Investigation has shown that practically all makers of tail-lamps are using glasses having a nominal diameter of 3 in. with tolerance of minus 1/64 in. and plus 1/32 in. These dimensions are recommended for standardization. Respectfully submitted,

ELECTRICAL EQUIPMENT DIVISION,

A. L. RIKER, *Chairman.*

DISCUSSION AT STANDARDS COMMITTEE MEETING

PAUL F. BAUDER:—The Division met yesterday and decided that inasmuch as there was some confusion regarding its work its name should be changed to Automobile Lighting Division. Before any recommendation can be made relating to head-lamp glare, it is believed that we should standardize the terminology with reference to various parts

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of the head-lamp itself. We have prepared a number of definitions relating to automobile lighting. Because of the various types, no definitions have been settled on for side-lamps and tail-lamps.

The Division believes that any formal preliminary report on the subject of the elimination of glare might obstruct its future efforts, especially in view of the necessity for coordination of the work of this Society with that of the Illuminating Engineering Society and the American Institute of Electrical Engineers. It is therefore felt that no additional recommendations as to the basis of future legislation should be made at this time.

CHAIRMAN CLAYDEN:—I suppose that the principal purpose of the definitions mentioned by Mr. Bauder is to facilitate standardization of dimensions so that everyone will know what is meant when certain tolerances or sizes are specified for certain things. The suggested change of name of the Division is a matter for the Council to settle and will be taken up with it in due course.

K. W. ZIMMERSCHIED:—This work appears to be largely coordinate with that of the Nomenclature Division. It should be reviewed by that Division and also by the Illuminating Engineering Society before it is accepted. I therefore move that this report be accepted by the Standards Committee for comparison and consideration before submission to the Society.

(The motion was seconded and carried.)

FIFTH REPORT OF ELECTRIC VEHICLE DIVISION

(As Adopted by the Society)

1—Standards for dimensions of the storage battery jars used on electric vehicles are proposed. Two types are recommended; the "high-rib" jars, having a height of 13⅝ in., and the "low-rib" jars, having a height of 12 7/16 in. The ribs are 2¾ and 1¾ in. high.

2—Both types have a width of 6⅛ in. and walls ⅛ in. thick; the use of 5/32-in. walls is optional, with the addition of 1/16 in. to all outside dimensions. The bottom thickness in both types is ¼ in. High-rib jars are listed in thirty-two lengths, ranging from 2 to 8¼ in. Low-rib jars are listed in nine lengths, ranging from 2 to 8 in. The dimensions proposed are given in Table I.

Standard Assemblies for Storage Batteries

3—The Division has laid plans for proceeding with the work of establishing standards for the arrangement of battery cells in trays.

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Lamp Bulbs

4—Proposals have been made looking toward the standardization of bulbs for electric vehicle lamps. Apparently the desired standards

TABLE I—DIMENSIONS FOR STORAGE-BATTERY JARS

Dimension*	High-Rib Jars, In.	Low-Rib Jars, In.
Height over all.....	13⅝	12 7/16
Width	6⅛	6⅛
Thickness of wall...	⅛	⅛
Height of rib above bottom of jar....	2¾	1¾
Height above rib...	10⅝	10 7/16
Lengths of jars....	2, 2 5/16, 2½, 2 9/16, 2 13/16, 3, 3⅛, 3 5/16	2, 2¾
	3½, 3 11/16, 3 13/16, 4, 4¼, 4 5/16, 4½, 4 25/32	3½, 4¼
	5, 5 5/16, 5½, 5¾, 6, 6¼, 6½, 6¾	5, 5¾
	6⅞, 7, 7¼, 7⅜, 7½, 7¾, 8, 8¼	6½, 7¼, 8

*Tolerance: + or — 1/32 in. for all dimensions except thickness.

have nearly been determined, but the Division is not yet ready to report them for adoption.

Respectfully submitted,
ELECTRIC VEHICLE DIVISION,
A. J. SLADE, *Chairman.*

FIRST REPORT OF ENGINE AND TRANSMISSION DIVISION

(*As Adopted by the Society*)

New engine testing forms have been prepared by the Division. There is a separate sheet containing rules and directions, one sheet (Fig. 1) for specifications of the engine, one (Fig. 2) to use as a log for recording both observed and calculated data, and one curve sheet (Fig. 3), with scales for recording the observed data in the form of curves. The four sheets are to be printed on 8½ by 11-in. paper. A supply will be kept at the office of the Society, where the sheets can be obtained at a nominal price. The matter contained in the Rules and Directions Sheet is given in this report, as are also reproductions of the other three sheets. Respectfully submitted,

ENGINE AND TRANSMISSION DIVISION,
W. T. FISHLEIGH, *Chairman.*

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S. A. E. ENGINE TESTING FORMS—RULES AND DIRECTIONS—A

S. A. E. Engine Testing Forms for recording engine tests consist of four sheets, as follows: (1) Rules and Directions, (2) Specification Sheet, (3) Log Sheet, (4) Curve Sheet. They can be secured at a nominal charge from the office of the Society of Automobile Engineers, in New York.

RULES AND DIRECTIONS FOR USE OF FORMS

Specification Sheet

(See corresponding numbers on sheet)

(2) Piston displacement, see tables, S. A. E. Handbook, Vol. I, sheets 42-42i.

(3) The compression volume is the volume occupied by the charge when the piston is at the top of the compression stroke. To measure this volume, with the piston on dead center at end of compression stroke (with both valves closed) fill the compression space from a graduate containing a known volume of light oil or kerosene. Care must be taken to correct for leakage. Total volume of cylinder = piston displacement + compression volume. Give compression pressure at 100 to 120 r.p.m., or at speed of standard starter.

(4) State number of cylinders cast integral, whether offset, type of cylinder head, whether water space is provided between adjacent cylinders.

(6) State whether water or air-cooled. If the former, state whether pump or thermosyphon. Note if two pumps or thermostat are used. State type of pump.

(7) Weight of piston with rings and pin should include weight of bushings, screws, or other piston-pin fastening devices in the piston. Record all weights in pounds and decimal parts thereof. In measuring length of piston and distance from center of pin to top of piston, deduct any chamfer or crown at top of piston.

(8) Specify whether rings are concentric or eccentric; give name, sketch or description of special types. If oil-ring is used, state location.

(9) In giving weight of connecting-rod, include weight of all bushings, bolts, screws, and oiling devices normally attached to the rod. For piston-pin see (7). The connecting-rod must be horizontal while the ends are being weighed, the ends being supported by knife-edges or arbors. For V-type engines, state lower end construction.

(10) Under location, state whether in connecting-rod or piston.

(12) Diameters and lengths of bearings are to be stated in order from front to rear.

(14) Describe contour of cam, such as, uniform acceleration, tangential.

(15 and 16) In case of non-poppet valves describe and give dimensions.

(17) Reciprocating parts of directly operated poppet valves include valve, valve-lifter, valve-spring retainer and lock, and half of valve-spring.

(19) To determine valve-timing, mark top and bottom dead centers on flywheel rim; also points at which each valve opens and closes, engine cold and tappets set for standard clearance. Measure with flexible steel tape the length of arcs thus marked on flywheel. Reduce to degrees. Check both top and bottom dead centers for engines with offset cylinders.

(20) Moment of inertia of the flywheel is to be given in mass (weight in pounds ÷ 32.2) and foot units. Moment of inertia is equal to the mass multiplied by the square of the radius of gyration. $I = M R^2$.

(21) The complete weight of engine should include oil, water, and all mechanically attached units necessary for normal functioning of engine, such as carbureter and its attachments, magneto, ignition distributor, generator, starting motor, fan and governor. Do not include such accessories as horn, tire-pump and vacuum tank. List weight of each item separately.

(24) State if heated by water or exhaust, and whether part or all of the air entering carbureter is heated.

(25) Under "general principles of operation" give description; as: "Venturi type with single adjustable nozzle and single auxiliary air-valve with one spring;" "straight-tube type, four non-adjustable nozzles coming into operation successively as air-flow increases."

(26) By description and sketch, give general form, approximate inside diameters of different portions, and specify which, if any, parts are jacketed.

(27) In case of two systems, state which was used in test.

(29) State if spark is fixed, or if spark control is automatic or manual. Maximum spark advance and retard are to be given in degrees of crankshaft rotation.

(30) Give material of insulation, number of sparking points on electrodes.

(31) In addition to exact location in combustion chamber, state whether vertical, horizontal or inclined, and whether plug extends into combustion chamber.

(32) Give the general type of lubrication system, as: "recirculating splash;" "force-feed and spray;" "complete force-feed." Then describe in detail action of system and course taken by oil. State oil pressures and type of pump used. State name and grade of oil used.

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S. A. E. ENGINE TESTING FORMS—SPECIFICATION SHEET—B

Name and Model _____ Date of Test _____

Manufacturer _____

*(1) General Type _____ Cycle _____

(2) No. of Cyls. _____ Bore _____ in., Stroke _____ in., Piston Displ. per Cyl. _____ cu. in., Total _____ cu. in.

(3) Compression Vol. (V_c) _____ cu. in., Total Vol. of Cyl. (V) _____ cu. in., Compression Ratio = $\frac{\text{Comp. Vol.}}{\text{Total Vol.}} = \frac{V_c}{V} =$ _____

Compression Pressure _____ lb. gage at _____ r. p. m.

(4) Type of Cyl. Casting _____ Matl. _____

(5) Type of Valves _____ Location _____

(6) Cooling System _____

(7) Piston, Type _____ Matl. _____

Wt. with Rings and Pin _____ lb., Length _____ in., Distance Center of Pin to Top of Piston _____ in.

(8) Piston-Rings, No. per Piston _____ Type _____ Width _____ in.

(9) Connecting-Rod, Type _____

Length, c. to c. _____ in. Weight, Upper End _____ lb., Lower End _____ lb., Total _____ lb.

(10) Piston-Rod Bearings, Diam. _____ in., Total Length _____ in., Matl. _____ Location _____

(11) Connecting-Rod Bearings, Diam. _____ in., Length _____ in., Matl. _____ Type _____

(12) Crankshaft Bearings, No. _____ Diam. _____

Material _____ Length _____

(13) Camshaft Bearings, No. _____ Diam. _____

Material _____ Length _____

(14) Type of Cams _____ Type of Valve-Lifters _____

(15) Inlet Valves, No. per Cyl. _____ o.d. _____ in., Port Diam. _____ in., Lift _____ in., Seat Angle _____ deg.

(16) Exhaust Valves, No. per Cyl. _____ o.d. _____ in., Port Diam. _____ in., Lift _____ in., Seat Angle _____ deg.

(17) Weight of Valve Reciprocating Parts, Inlet _____ lb., Exhaust _____ lb.

(18) Valve-Spring Tension, Inlet Open _____ lb., Closed _____ lb., Exhaust Open _____ lb., Closed _____ lb.

(19) Valve-Timing, Inlet Valve Opens _____ deg. _____ Top Center, Closes _____ deg. after Lower Center

Exhaust Valve Opens _____ deg. before Lower Center, Closes _____ deg. _____ Top Center

(20) Flywheel, o.d. _____ in., Weight _____ lb. Moment of Inertia _____

(21) Weight of Engine _____ lb., Including _____

CARBURETION

(22) Carburetor, Name and Model _____ Nom. Size _____ in.

(23) Specifications (Size of Nozzles, etc.) _____

(24) How Heated _____

(25) General Principles of Operation _____

(26) Description of Intake Pipe _____

IGNITION

(27) Name and Type of System _____

(28) Type of Distributor _____ Firing Order _____

(29) Type of Breaker _____ Maximum Spark Advance _____ deg., Retard _____ deg.

(30) Spark-Plugs, Name and Type _____ Size _____ in.

(31) Location _____ Gap _____ in.

LUBRICATION SYSTEM

(32) Type and Description _____

*See Notes Corresponding to Numbers Under "Rules and Directions"

FIG. I—REPRODUCTION OF SPECIFICATION SHEET OF TESTING FORMS

Log Sheet and Curve Sheet

The Log Sheet and Curve Sheet have been designed for conveniently recording data and plotting curves covering the usual Standard Engine Tests. For special tests, these may be modified or special forms used.

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GENERAL RULES AND DIRECTIONS

A complete Standard Engine Test includes the determination at different speeds of: (1) Max. hp.; (2) Fuel economy at max., at ¾, at ½ and at ¼ max. hp. at each of the speeds; (3) Friction-hp. From these determinations, the following curves are plotted on the Curve Sheet:

(1) Torque—r.p.m.
(2) Max. hp.—r.p.m.
(3) Brake m.e.p.—r.p.m.
(4) Friction-hp.—r.p.m.
(5) Mechanical eff.—r.p.m.
(6) Fuel per b.hp. per hour, max. hp. at each speed.
(7) Fuel per b.hp. per hour, ¾ max. hp. at each speed.
(8) Fuel per b.hp. per hour ½ max. hp. at each speed.
(9) Fuel per b.hp. per hour, ¼ max. hp. at each speed.
(10) Thermal eff., max. hp. at each speed.
(11) Thermal eff., ¾ max. hp. at each speed.
(12) Thermal eff., ½ max. hp. at each speed.
(13) Thermal eff., ¼ max. hp. at each speed.

Emphasis is laid upon the value of the determination, in addition to the usual runs at max. hp. at each speed, of fuel consumption and thermal efficiency at each speed with the engine developing ¾, ½ and ¼ of its max. hp. *at that speed.* Automobile engines operate a large proportion of the time on part load, and in the study of the operating characteristics of engines, these curves are of great importance. During the max. hp. run at any speed, the max. torque (or load) is determined. For runs at ¾, ½ and ¼ max. hp. at the same speed it is only necessary to set the torque (or load) at ¾, ½ and ¼ the maximum for this speed and make proper throttle setting for such load.

During the complete test, control of engine shall be by means of throttle and spark only. Engine adjustments shall be made for best horsepower output (that is, carbureter setting, spark plug gaps, etc.), and in no case are such adjustments to be changed during the complete test.

Test runs should not be made until the engine has been run-in sufficiently to show no appreciable difference in friction before and after a run of 30 min. at the speed of maximum torque with the throttle wide-open.

Where test is to be made of a stock engine, all parts, accessories, lubricants, etc., must be stock. In every case, all regular equipment must be on the engine and operating (for example, fan, generator, etc.).

Before beginning any run, the engine should be brought to a condition of sustained operation under the conditions of the run and it is imperative that in every case r.p.m., brake loads, rate of fuel consumption, cooling-water temperatures, oil temperature, air draft, etc., remain substantially constant, steady and sustained throughout the run. Flash readings and tests are unscientific and misleading.

Number of Runs

In every test, enough runs should be taken throughout the speed range so that the points therefor when plotted will indicate clearly the shape and characteristics of the curves. For horsepower and fuel economy tests, it is recommended that runs be made at intervals of approximately 200 r.p.m. A run should be made at the lowest steady operating speed of the engine. All points from which curves are plotted are to be clearly shown on the Curve Sheet.

Duration of Runs

The duration of Brake-horsepower tests shall not be less than 3 min. Where Fuel Consumption is measured, the duration of tests shall not be less than 5 min. The duration of Friction-horsepower tests shall not be less than 1 min. The above stated times are minima. In most instances it is desirable to make the runs of longer duration, and it is imperative that in every case r.p.m., brake loads, rate of fuel consumption, cooling-water temperatures, oil temperature, air draft, etc., remain substantially constant and steady throughout the run.

Balancing Dynamometer

Before any readings of Brake Load are recorded, great care should be exercised to see that the dynamometer itself is properly balanced. For the electric-cradle type of dynamometer this balancing is accomplished as follows:

The dynamometer is run idle as a motor (drawing current from the line) and a suitable counterbalance on the field frame—which should be perfectly free to turn within limits in ball bearing trunnions—is then adjusted so that the platform scales read zero. This reading should be obtained with the dynamometer rotating first in one direction and then in the other. The reaction of the armature on the field frame will exactly balance the friction of the brushes and armature bearings carried in the field frame. With the armature still rotating, check-weights (or pieces of metal having a known weight) should be hung from the knife-edge on the dynamometer arm. If the reading recorded by the platform scales is equal to the known weight applied, the dynamometer can be considered as balanced.

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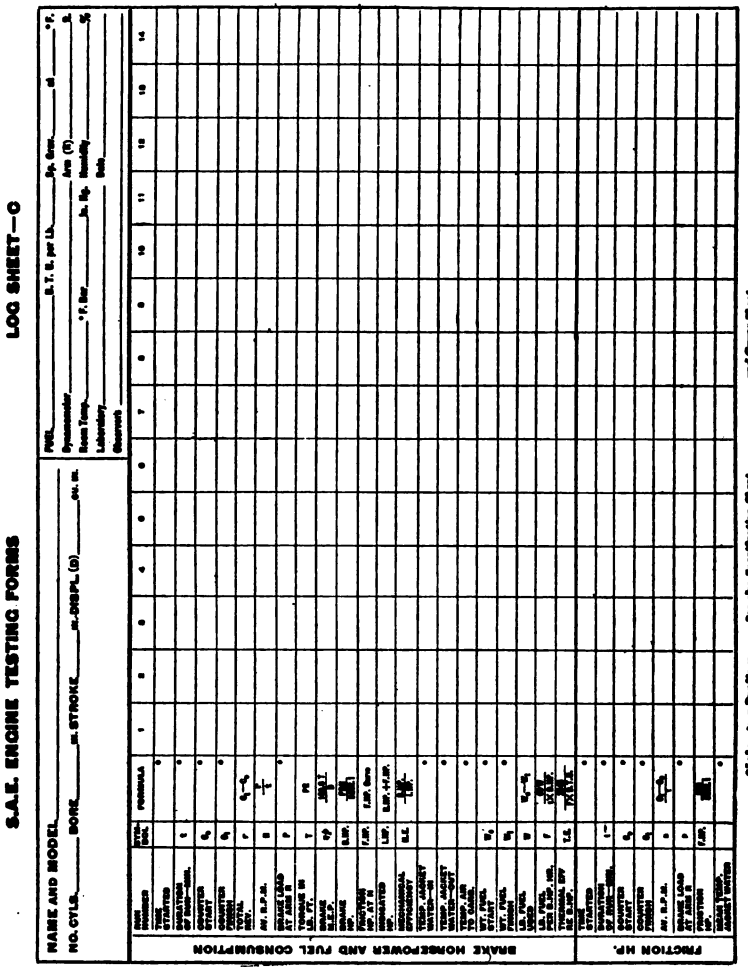

FIG. 2—REPRODUCTION OF LOG SHEET OF TESTING FORMS

Brake Loads

Readings for Brake Loads should be taken with accurately calibrated platform or beam scales. The connection of the dynamometer arm to these scales by means of knife-edges, calibrated spring balance and tripod or suitable linkage is recommended. Suitable counterbalances or tare loads must be accurately provided. The spring balance gives a quick approximate reading for Brake Load; it serves to cushion the platform or beam scales from shock and vibration. During any run, the platform or beam scales are kept balanced, and the loads registered thereby must be substantially constant and steady throughout the run.

Revolutions Per Minute

Speed in revolutions per minute should be invariably taken from positively driven counters which engage at the beginning of the run and disengage at the end. The difference between the two readings, divided by the duration of

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run in minutes, then gives the true average speed. Tachometers, even though carefully calibrated, are not sufficiently reliable for r.p.m. readings. In connection with the speed counters mentioned, however, the tachometer may be used as an approximate check on average speed, also as an indicator of variations in speed before or during the run.

It is recommended that the maximum allowable variation in speed during a run shall be 50 r.p.m.

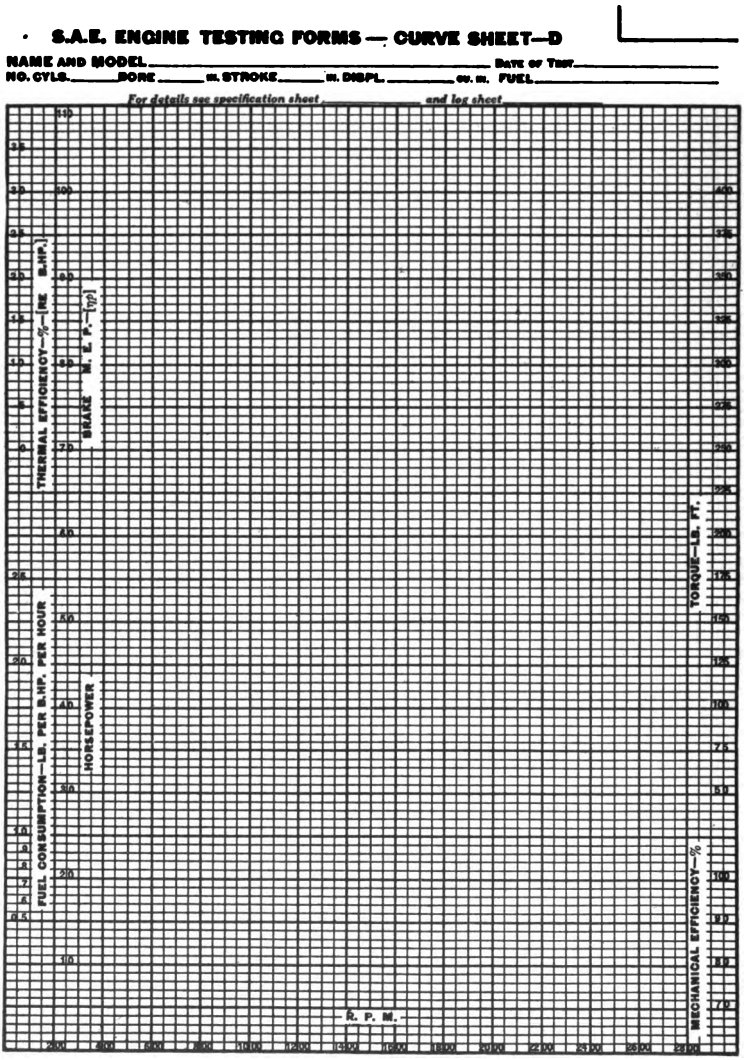

FIG. 3—REPRODUCTION OF CURVE SHEET OF TESTING FORMS

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Fuel Consumption

The method recommended for measuring fuel consumption is by noting the decrease in weight of a tank from which fuel is being fed to the carbureter. The tank should be placed on sensitive platform scales at a proper level above the carbureter, and connected to the fuel-supply pipe by a short horizontal length of rubber tubing. This tubing should be very flexible and should not be drawn taut, to avoid interference with the weighing. Weighings should be made as follows:

Set counterpoise so that scale-beam will fall just as run is started. Note the setting and the time at which the scale-beam falls. Move the counterpoise back to the next pound mark, or to such a point that it will fall just before the end of the run, and note carefully the time when beam again falls. From the difference between the two times and the two weights recorded, the fuel consumption per hour can be readily determined.

The counterpoises may be successively set back for small quantities (say ¼ or ½ lb.) and the times noted during the progress of the run. This gives an indication of the steadiness of fuel consumption throughout the run, and in no wise interferes with the major measurements outlined in the previous paragraph.

Temperatures

All temperatures are to be given in degrees Fahrenheit.

A reliable glass straight-stem thermometer should be placed near the carbureter air-inlet in order to measure the temperature of the entering air. This thermometer should be read at least three times during each run one of these times to be at beginning and one at end of run.

Thermometers should be placed also in suitable wells or sockets, one near the inlet of the pump and another as close as possible to the water-outlet of the engine. These wells or sockets should be in pipes that run full, so that water continually circulates about them. They should be filled with oil or mercury, and careful readings taken at least three times during each run, one of these times to be at beginning and one at end of run.

In order to afford a fixed basis of comparison, it is recommended that the outlet water temperature for engines be kept at 175° Fahr. (+ or — 5°). Control of the outlet temperature can be accomplished by thermostat located in the outlet line or by external control of quantity or temperature of inlet water. Where thermostat or other cooling water regulating devices are standard upon an engine, these may be attached and operating during a test.

In every case, inlet and outlet cooling-water temperatures should remain substantially constant and steady throughout a run. It is recommended that the maximum allowable variation in cooling water temperature shall be 10 deg. F.

During friction-horsepower runs it is desired to obtain the mean temperature of the jacket water. If the water is pump-circulated, the average of the inlet and outlet temperatures may be taken. If thermosyphon circulation is used, the water will not circulate noticeably during a friction-horsepower run. The mean jacket-water temperature for such engines can be taken by inserting thermometers into the jacket space, the average of readings being taken. In every case of friction-horsepower test, the test must be made immediately after the corresponding brake-horsepower test, before the engine has cooled.

An air draft should be provided which approximates in amount and effect the air draft on the road with the car moving at a speed corresponding to the given engine speed. During friction-horsepower tests, of course, this air draft is shut off, in order not to cool the engine.

For air-cooled engines, the air draft is of the greatest importance.

Friction-Horsepower

The approximate friction-horsepower of an engine can be measured best by means of an electric dynamometer, preferably of the cradle type. The dynamometer is used to drive the engine under test at various speeds, and the torque reaction is measured. This will be in the opposite direction to that obtaining while the engine is driving the dynamometer, so that provision must be made for measuring the torque on both sides of the dynamometer, or else suitable linkage must be provided to change the direction of the pull. The test for friction-horsepower should be made immediately after the brake-horsepower test, before the engine has cooled, in order to keep the condition of the lubricating oil and the friction of the parts the same as during the brake-horsepower test, as nearly as possible. During this test the throttle of the engine should remain in the same position as for the corresponding brake-horsepower test. Compression-relief cocks should remain closed and all accessories, such as magneto, generator, pumps, etc., used during the brake-horsepower test, should be in operation. See notes on friction-horsepower runs under the various headings.

Indicated-Horsepower

Approximate indicated-horsepower is obtained by adding to the brake-horsepower at any given speed the friction-horsepower obtained at the same speed.

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If the friction-horsepower and brake-horsepower tests are not made at exactly the same speeds, the friction-horsepower at any given speed can be obtained from the friction-horsepower curve plotted on the Curve Sheet. Tedious interpolation is thus avoided.

DISCUSSION AT STANDARDS COMMITTEE MEETING

PROF. W. T. FISHLEIGH:—The engine testing forms have been finally revised. A number of detail changes have been approved by the Division. The final set of forms, which were approved by the Committee at the Washington meeting, will be presented to the Society to-morrow.

The matter of hand starting-cranks has been considered at length in the Division. At first it was thought that we might recommend complete standard dimensions, but on reconsideration we have tentatively decided upon about half a dozen dimensions. Drawings have already been made and will be submitted to starting-crank and automobile manufacturers in the near future.

TABLE I—PROPOSED VALVE DIMENSIONS

Nominal Valve Diameter	Stem Diameter	Nominal Valve Diameter	Stem Diameter
1	0.3090 0.3100	2	0.4340 0.4350
1⅛	0.3090 0.3100	2⅛	0.4340 0.4350
1¼	0.3090 0.3100	2¼	0.4340 0.4350
1⅜	0.3715 0.3725	2⅜	0.4965 0.4975
1½	0.3715 0.3725	2½	0.4965 0.4975
1⅝	0.3715 0.3725	2⅝	0.4965 0.4975
1¾	0.3715 0.3725	2¾	0.4965 0.4975
1⅞	0.4340 0.4350	3	0.4965 0.4975

We have considered engine-support arms and find many difficulties in the matter of standardization. Drawings will be submitted in order to get general opinions from the industry.

We hoped to make definite recommendations regarding poppet-valve dimensions at this meeting. Some interesting discussion developed in our Division meeting yesterday, so that I want to make only a progress report.

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We started to consider the standardization of a dozen or more dimensions, but after circularizing the industry, concluded that either the standardization of all dimensions was not desirable or else we are not ready for this at present. We have come to a general conviction in the Division that it is advisable to standardize the dimensions given in Table I.

These include a dimension for the nominal diameter of the head of the valve, taken as the small diameter of the conical seat; a corresponding dimension for the stem, leaving the length indefinite to suit the particular case; a draft angle of 7 deg. on the head, which seems to be universally satisfactory; a 45-deg. seat, which has been generally approved; also a slot in the head of the valve without specifying the detail dimensions.

The intention of the Division is to place manufacturing limits upon the stem dimensions; these are agreed upon from the standpoint of proper clearance in the reamed hole, which would, of course, come in the valve-stem guide.

TENTH REPORT OF THE IRON AND STEEL DIVISION

(As Adopted by the Society)

The Division recommends the elimination of the specification* for malleable cast iron from the list of S. A. E. standards. Respectfully submitted,

IRON AND STEEL DIVISION,
K. W. ZIMMERSCHIED, *Chairman.*

NINTH REPORT OF THE MISCELLANEOUS DIVISION

(As Adopted by the Society)

The Division recommends the adoption of No. 8—32 (0.164 dia.) A. S. M. E. standard thread for spark-plug terminals.

Respectfully submitted,

MISCELLANEOUS DIVISION,
JOHN G. UTZ, *Chairman.*

*See S. A. E. TRANSACTIONS, Part II, 1915, p. 31.

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SIXTH REPORT OF THE SPRINGS DIVISION

(As Adopted by the Society)

1—This report contains recommendations relating to rebound clips with spacers and bolts, purchase of cantilever springs and leaf points.

Rebound Clips With Spacers and Bolts

2—Tentative specifications of data on rebound clips furnished by spring manufacturers and tabulated by the Division were submitted to fifteen spring manufacturers, forty-one pleasure car manufacturers and eleven truck manufacturers. Replies and comments

TABLE I—DIMENSIONS FOR REBOUND CLIPS, SPACERS AND BOLTS

Dimensions (See Fig. 1)	For Pleasure-Car Springs (Except Cantilevers or when wider than 2½ in.)	For Commercial-Car Springs (Also Cantilevers on Pleasure Cars)	
		2¼, 2½, 3 in. wide	3½ in. wide & over
A	*	*	*
B	†	†	†
C	3/16	¼	¼
D	⅛	3/16	3/16
E	¾	1	1¼
F	⅜	½	⅝
G	7/16	⅝	¾
H	11/32	13/32	13/32
I (dia. rivet)	5/16	⅜	⅜
J (omit with inverted clips)	11/32	13/32	13/32
K	5/16	⅜	⅜
L	5/16—18 U.S.	⅜—16 U.S.	7/16—14 U.S.
M	7/32	7/32	25/64
N	½	9/16	25/32
O	7/32	7/32	7/16
P	½	9/16	25/32
Q	**	**	**
R	7/16	½	⅝
S (B. W. G.)	Not less than 20 (0.035 in.)	18 to 20 (0.049 to 0.035 in.)	15 to 17 (0.072 to 0.058 in.)

*To be 1/32 to 1/16 in. greater than nominal width of spring.
†To be made to suit spring.
**To be 1/32 in. greater than nominal width of spring.

were received from five spring makers, eighteen pleasure car makers and four truck makers. Some changes in the dimensions of the largest clip bolt were suggested by the truck and spring manufacturers. The dimensions (Table I and Fig. 1) meet with approval of twenty manufacturers and the substantial approval of five other manufacturers and are submitted for acceptance.

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Purchase Specifications for Cantilever Springs

3—The Division recommends that sketches (Figs. 2 and 3) showing the dimensions for cantilever springs be added to the S. A. E. specifications for the purchase of leaf springs.

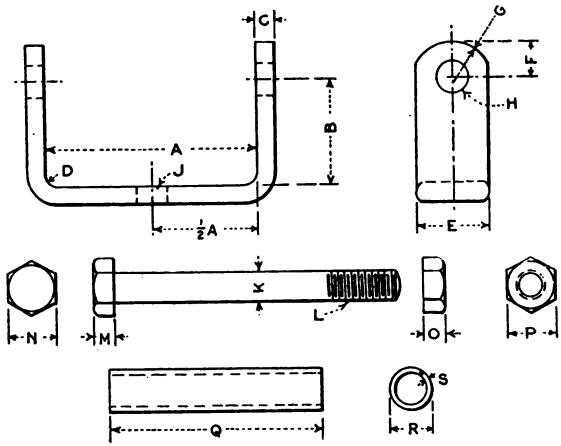

FIG. 1—REBOUND CLIP WITH SPACERS AND BOLTS

Leaf Points—"Trimmed End"

4—The Division recommends adding to the list* of spring leaf points the type known as the "trimmed end," in which the end of the leaf is not reduced in the section by forging but by trimming at the sides, making a pointed leaf end of the same thickness as the rest of the leaf.

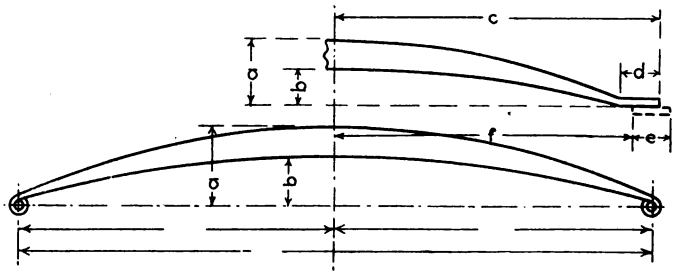

FIG. 2—SHOWING DIMENSIONS TO BE SPECIFIED FOR CANTILEVER SPRINGS

*See S. A. E. TRANSACTIONS, Part I, 1913, p. 73, or S. A. E. Handbook, Vol. I, sh. 49b.

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5—The unfinished work of the Division consists of the following items: Spring shackle bolt, threaded ends and nuts; spring clips: length of spring seat and clip spacing; and finish of spring leaves.

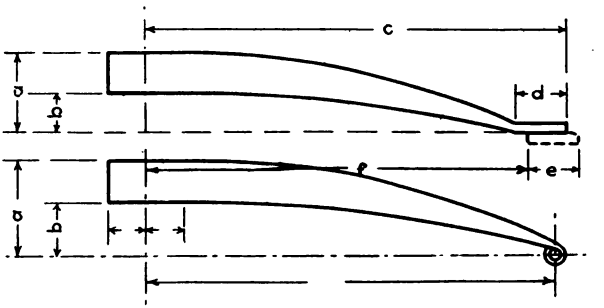

FIG. 3—SHOWING DIMENSIONS TO BE SPECIFIED FOR CANTILEVER SPRINGS

6—This report has been submitted for consideration to four members of the Springs Division, which consists of six members, of whom four have voted affirmatively and two have refrained from voting.

Respectfully submitted,

SPRINGS DIVISION,

C. W. MCKINLEY, *Chairman.*

FIRST REPORT OF THE TIRE AND RIM DIVISION

(As Adopted by the Society)

1—At this time the Division makes a specific recommendation relating only to solid-tire widths. The subjects of carrying capacities and inflation pressures of pneumatic tires, types of rims for pneumatic tires and solid-tire channel-contours are under consideration.

Solid-Tire Widths

2—It is recommended by the Division that the standard width of solid tires be defined as the "nominal" width in inches as measured inside the channel (see Fig. 1) at the mean of the vertical seat of the rubber, the tolerances being plus or minus 1/16 in.

Carrying Capacities and Inflation Pressures of Pneumatic Tires

3—The Division has this important subject under active consideration and hopes to make a final report embodying a table of standard or recommended practices at the next Standards Committee meeting.

Types of Rims for Standard Pneumatic Tires

4—This subject is also under active consideration. The Division is

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cooperating with the Clincher Automobile Tire Manufacturers' Association and will probably submit a report at the next meeting.

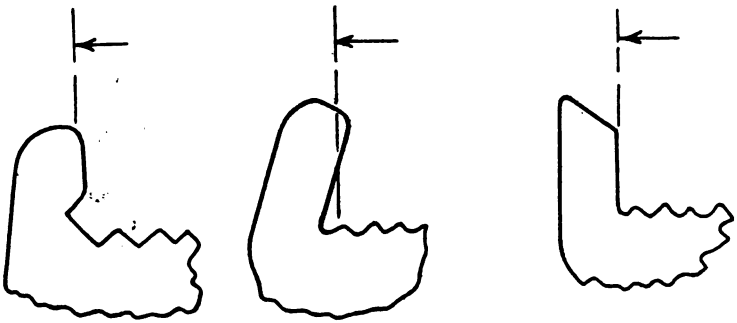

FIG. 1—SHOWING POINTS AT WHICH NOMINAL WIDTH IS MEASURED

Solid-Tire Channel-Contours

5—Preliminary discussion has been held on the advisability of evolving a standard channel section for pressed-on and demountable solid tires. The development of this standard will probably take considerable time, but it is believed that the possible advantages to be gained are considerable; the Division hopes to make material progress on the question soon. Respectfully submitted,

TIRE AND RIM DIVISION,
K. W. ZIMMERSCHIED, *Chairman.*

DISCUSSION AT STANDARDS COMMITTEE MEETING

K. W. ZIMMERSCHIED:—The Division had a session yesterday and adopted a report, recommending carrying capacities for solid tires and a definition of their nominal width.

A. L. RIKER:—How do the proposed carrying capacities compare with the present accepted practice?

K. W. ZIMMERSCHIED:—The proposed carrying capacities are less than many of those used in accepted practice; that is, they are on the conservative side, although they are in some cases over the rated capacity that the tire makers list.

J. E. HALE:—I would like to caution the Standards Committee, as I believe that the carrying capacities for the 5, 6 and 7-in. tires of the 40-in. diameter are too high.

M. C. HORINE:—I believe that mention should be made of the wider sizes of solid tires that are now on the market and are being developed by several companies—8, 10, 12 and 14 in. Now is the time

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to standardize those carrying capacities, before manufacturers get them out generally.

C. B. WHITTELSEY:—The tire men have been about five years at work on these capacities and have discussed this thing pro and con in order to prepare a table of carrying capacities of tires that is as nearly correct as possible, at the same time not putting any more hardships on the manufacturers of motor trucks than we could possibly help. We realize that there will be legislation relating to carrying capacities of solid tires, and we are trying to establish an absolutely correct list.

K. W. ZIMMERSCHIED:—The question has not been so much what is present practice as what is decent treatment to give a tire; higher loads than these would be a great injustice to the tires, and in some cases to the tire people, the users and the truck manufacturers.

C. B. WHITTLESEY:—It is impossible at this time to establish a standard for wide solid tires; there are not enough of the very wide tires and we have not had enough experience with them to include their capacities.

C. C. CARLTON:—I call attention to the increased values in the recommended table as compared with those now suggested by one tire maker. For 3 in. the tables are the same; for 3½ in. they show an increase of 30 lb. per wheel; 4 in., an increase of 100 lb.; 5 in., an increase of 500 lb.; 6 in., an increase of 800 lb.; 7 in., an increase of 1,200 lb. per wheel, from a former 3,000 to 4,200 lb. now. These are for the 36 in. and smaller sizes. On the larger sizes it will be from 2,200 to 2,600 lb. on the 5 in.; from 2,750 to 3,500 on the 6 in., and from 3,500 to 4,500 lb. on the 7-in. tires.

The tire companies at least have done everything in their power to increase the capacities as much as they feel is within the bounds of safety and justice to the tire.

DISCUSSION AT SOCIETY MEETING

JOHN YOUNGER:—I believe that the report should not be adopted. Many of the recommended carrying capacities are wrong. The truck manufacturers are distinctly interested in this and we ought to have time to consider it. I will only make special reference to one size, and that is the 6-in., for which carrying capacities of 3,300 lb. on a 36-in. tire and 3,500 lb. on a 40-in. tire are proposed. That 3,500 lb. works out as 14,000 lb. gross for dual tires. For the last six years we have been carrying 16,000 lb. on our trucks with dual tires very satisfactorily. The Goodrich company has claimed that mileages of 24,000 have been obtained with its 6-in. dual tires, with

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16,000-lb. gross load. The guaranteed mileage is 7,000 miles. Tires are getting better, roads are getting better and the drivers are getting better, and for this reason I would ask that this matter be further considered.

Much consideration is being given to this question. I recently attended a meeting of the New Jersey State Highway Commissioners; they have proposed legislation that would prevent any truck having a carrying capacity greater than specified in this report from running on their highways; the result would be great injustice to manufacturers and owners. S. A. E. standard carrying capacities will undoubtedly be taken up by State Highway officials, and for this reason alone we should consider this table very carefully in all its aspects.

J. E. HALE:—There is just so much mileage built in tires and that mileage is affected by the load that the tires carry; the more load they carry the less service will they give. There is no sharp line at which a tire is overloaded. In reality the overloading point is determined by the satisfaction that users receive and what they consider satisfaction. It has been pointed out by Mr. Younger that certain tires are reported as being satisfactory. Maybe they are as far as he knows. But for commercial reasons the reputable tire companies are most careful to see that the complaints do not get back to the truck manufacturers.

The more adequate tire equipment put on a truck the less the tire cost per mile to the consumer. If we choose carrying capacities that are conservative and safe and sane, we are doing the public and the truck business the greatest favor that can be done. This Society can adopt the figures if it wants to, but it cannot make the tires give more service.

B. B. BACHMAN:—Is the Society asked to standardize a set of figures based on mature deliberation and tests and therefore figures that are established on a scientific basis, or are these figures simply the result of compromise between representatives of the tire manufacturers and based upon information that they may have in their own hands but that has not been made public? Have the data upon which these figures have been based been put in the possession of the Division that has established these figures and in the hands of the Standards Committee when the report was submitted to it?

There has been an agitation in the Society for some years for the establishment of load-carrying capacities. The stumbling block to such action in the past has been the plea on the part of almost every one who has had anything to do with the thing, that there was no scientific basis on which figures could be based. There has been a wide difference of opinion among all of those interested as to just what the basis should be.

Some three years ago, I believe, Mr. Hale indicated an outline of proposed tests in a paper * he presented at the 1914 Semi-Annual

*Motor Truck Tires, J. E. Hale, S.A.E. Transactions, Part II, 1914, p. 107.

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Meeting. Since that time, I believe, some tests have been made, but I do not know that the results have ever been published or that adequate data have been available upon which to base this table.

K. W. ZIMMERSCHIED:—I will state to Mr. Bachman that the Goodrich company submitted a complete set of data in connection with its remarks on what these capacities should be. The figures for the 40-in.-and-over sizes represent the maximum values that would be considered good mileage from the tires used in the Goodrich tests.

The Goodyear company also submitted blueprints showing curves of tire life based on elaborate tests. We have asked for a set of those prints to include in the record; they were presented and they were taken into consideration. Those curves were studied with the idea of allowing, if possible, higher loads so that the mileage would, perhaps, not be reduced too much. We want to arrive at a reasonable mileage with a reasonable load.

We were asked specifically by the Truck Standards Division to prepare a table of carrying capacities, because of threatened legislation. We understand that certain legislatures are waiting for such a table before they establish commercial vehicle taxation schedules.

G. A. GREEN:—I believe some figures obtained in the operation of the Fifth Avenue Coach Company's equipment bear on the subject. Our new "A" type buses, which are equipped with 4-in. dual rear tires, under conditions of maximum load carry 2965 lb. per tire or 74 per cent in excess of the 1700 lb., as shown by the proposed table. This new equipment has covered more than half a million miles, and from results obtained so far we have every reason to believe that we are working in the right direction. I confidently anticipate that when we are operating only standard "A" type buses our tire cost will be less than 1 cent per bus-mile. This low cost is obtainable largely because our unsprung weight has been reduced to the minimum.

The fitting of larger tires means an immediate increase in unsprung weight. Every time such weight is added tire mileage is reduced. There is a distinct dividing line between the tire that is too large and the tire that is too small. I think we have found the happy medium, and as far as I am concerned—while I, of course, do not speak officially—we would be willing to forego the tire companies' guarantee rather than increase the size of the tires. The additional weight of oversize solid tires, their steel bands, etc., is not the only factor one must take into account. The use of larger tires means larger wheels and, in fact, a general strengthening up becomes necessary. It may be said that no comparison can be made between the operation of the Fifth Avenue Coach Company's buses and that of trucks; while this may or may not be the case, I believe that the table should receive further study.

A. L. RIKER:—Inasmuch as these carrying capacities were pre-

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pared for the Truck Standards Division, I suggest that the matter be referred to that Division before any action is taken on it by the Society at large.

(On motion, duly seconded, it was voted to refer the matter of carrying capacities of solid tires to the Truck Standards Division; and to approve the remainder of the report of the Tire and Rim Division for submission to the Members by letter ballot.)

FIRST REPORT OF TRUCK STANDARDS DIVISION

(As Adopted by the Society)

1—The Division recommends standards for the following control elements of motor trucks: Gearshift and hand-brake levers, gearshift lever-handle positions, clutch and brake pedals, accelerator pedal, spark and throttle hand-levers.

Gearshift and Hand-Brake Levers

2—Gearshift and hand-brake levers shall be placed at the driver's right, with the hand-brake lever to the right of the gearshift lever. The hand-brake lever is to be pulled back for brake application. The gearshift lever is to be fitted with a latch guarding the reverse position, or the equivalent of a latch, when used with either a three or a four-speed transmission.

Gearshift Lever-Handle Positions

3—For three-speed transmissions the positions of the gearshift lever-handle shall be the same* as standardized for pleasure cars. Four-speed transmissions are to have the forward speeds so arranged that the gearshift handle in high speed is in the same position as with the three-speed transmission, low speed occupying the place of reverse, as shown in Fig. 1. The location of the reverse position is to be left optional. With either three-speed or four-speed transmissions, the various speeds shall be clearly indicated, either on the gate or at the base of the gearshift lever.

Clutch and Brake Pedals

4—The clutch pedal shall be located to the left of and the foot-brake pedal to the right of the fore-and-aft center line of the steering column.

Accelerator Pedal

5—The accelerator pedal shall be placed to the right of the brake pedal.

Spark and Throttle Hand-Levers

6—Spark and throttle hand-levers, if used, should be located to

*See S. A. E. TRANSACTIONS, Part II, 1916, p. 23, and S. A. E. Handbook, Vol. I, sh. 46.

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the right of the fore-and-aft center of the steering column. The spark lever should be the shorter of the two and both levers carried

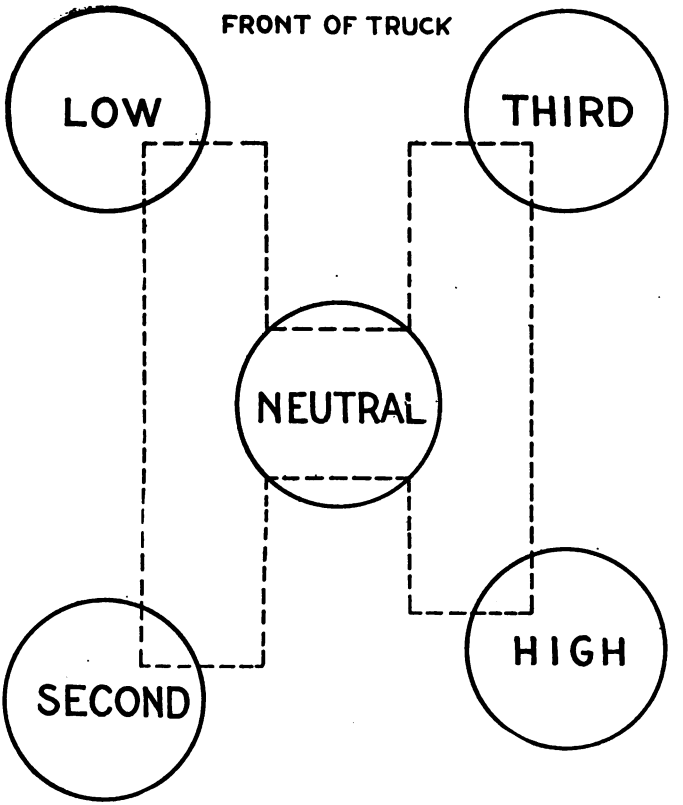

FIG 1—GEARSHIFT POSITIONS FOR FOUR-SPEED TRUCK TRANSMISSIONS

on stationary sectors. Both levers should be arranged so that they are pushed forward to advance the spark and to open the throttle.

Respectfully submitted,

TRUCK STANDARDS DIVISION,

H. D. CHURCH, *Chairman.*

DISCUSSION AT STANDARDS COMMITTEE MEETING

A. L. RIKER:—About six or eight months ago the United States Government sent out specifications for a military truck. These specifications were referred to a special committee of this Society appointed to confer with the Government officials. The committee was finally made permanent and is known as the Truck Standards Division at present. The Division has held several meetings

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and has gone over the specifications both with the representatives of the Government and alone. At present, the Government is revising the specifications and asking the Division to assist wherever possible.

Early in January a meeting was held in Washington which was attended by members of the Truck Standards Division and by army officers who are handling transportation matters. At that time various questions regarding specifications were discussed and members of the Division made suggestions for further revision. It is understood that the specifications are being revised in accordance with our suggestions and that they will be submitted to the Truck Standards Division for further consideration.

CHAIRMAN CLAYDEN:—I believe that so far as the quality and character of the military specifications are concerned, the work done by the Truck Standards Division and by the Society generally will be of great assistance both to the Government and to the Society.

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BUSINESS AND PROFESSIONAL SESSIONS OF SOCIETY MEETING

PRESIDENTIAL ADDRESS OF RUSSELL HUFF

The most eventful year in the Society's history is being concluded. Unexpected expansion in the automobile industry has been followed by a remarkable increase in the membership and activities of the Society. The purpose for which the Society was organized was "to promote the Arts and Sciences and Standards and Engineering Practices connected with the design and construction of automobiles, all forms of self-propelled or mechanically-propelled mediums for the transportation of passengers or freight, and internal-combustion prime movers." Prominent engineers in the tractor, airplane, motor ship and stationary gas engine industries have been suggesting for a number of years some form of affiliation, whereby their respective industries could be represented in the Society and on its Standards Committee and could benefit by belonging to a strong organization, carrying on its work with efficiency and dispatch.

All these industries depend on the internal-combustion engine for motive power. They have grown in magnitude with startling rapidity in the last year. The need for proper standards in each respective field is all important now as they emerge from the experimental or developmental period to one of great commercial activity. One of the fundamental reasons for the continued and rapid growth of the automobile industry is the pioneer work done by the Society in the past years.

The Society of Automobile Engineers is the logical institution to father the all-important standards work and promote every phase of the arts and sciences in these rapidly growing industries. Modern transportation methods are revolutionizing business and war. The horse has had its day, the railroad its inning and now the automobile and motor truck are necessities in our every-day life. The airplane, the tractor and the motor ship are exhibiting new possibilities in transportation that bid fair to bring about even more startling changes than have the automobile and motor truck.

Of the many suggestions offered during the past year in furtherance of the movement, probably the most notable one is that of substituting the word "Automotive" for "Automobile" in the name of our present Society. This proposal, when put to the members at the 1916 Semi-Annual Meeting, was heartily indorsed. The new and

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broader title, including as it does a word applicable to any transportation conveyance, is a most fitting name for the greater organization that is sure to follow the merging of the allied societies.

The Council has passed a resolution permitting members in good standing in the other societies to come into the proposed "Society of Automotive Engineers" without the payment of the usual initiation fee, provided the application is filed with us within three months from a date to be fixed by the President after the respective societies have voted to make the change.

The amalgamation with the American Society of Aeronautic Engineers is well under way. A large number of the members of that society have become members of the S. A. E., or have filed application for membership. The Council of the Society of Tractor Engineers has recommended that its members consolidate with the S. A. E. under the proposed conditions. The executive committee of the National Association of Engine and Boat Manufacturers has voted favorably on this plan. We expect the National Gas Engine Association and the American Society of Agricultural Engineers to cooperate in carrying on our standardization work.

COOPERATION WITH THE GOVERNMENT

Cooperation with the Government is an impressive feature of our present work. This Society represents an essentially modern and progressive industry. Because of that fact and because of the effective work it has done during the past several years, the S. A. E. has received distinctive recognition from the Government. The Truck Standards Division of the Standards Committee is helping the War Department Staff to formulate suitable military truck specifications. The Aeronautic Engine Division of the Standards Committee has been authorized by the Council to cover the aeronautic field. This Division is already in active cooperation with various Government departments in formulating specifications and standards suitable for this new and rapidly developing industry. A Tractor Standards Division will be chosen to consider the increasing number of perplexing questions arising in this field. We are cooperating with the Bureau of Standards on a number of important problems, including that of gasoline specifications.

We are also in close touch with the commercial and users organizations of the various industries. We are working with the National Automobile Chamber of Commerce in connection with such problems as head-lamp glare, carrying capacity of solid tires and engine-number location. We are engaged in various activities with the American Automobile Association, The Automobile Club of America, The Safety First Federation of America, The Motor Truck Club and The New York Automobile Dealers' Association.

The Society has gained substantially in membership during the year. On Jan. 1, 1916, there were 1783 members. During the year 337 members have joined, making the present total 2120 members. This does not include the Section Associates. The increase in

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membership during the year has put the Society in a better financial condition than ever before. In 1910, when the Society began the real standardization work, the funds necessary to carry on the work were personally guaranteed by a few of the prominent engineers of that time. While the annual budget is many times what it was several years ago, owing to greater office rent, salaries, printing expense and standardization work, the income from initiation fees, dues, advertising and other sources has kept pace with the increased expense.

WORK OF THE SECTIONS OF THE SOCIETY

The several Sections deserve great credit for the important part they have played during the year in keeping up the general interest of the members in the Society's work. I have attended Section meetings in New York, Cleveland, Indianapolis and Detroit and assisted in the organization of a new Section in Buffalo. The many enthusiastic meetings held by the Sections have benefited the Society at large through the increased number of valuable papers obtained for the S. A. E. BULLETIN, through additions to the membership, through wider publicity given the standards work and through the expanding interest in S. A. E. activities among the manufacturers. We should encourage the Section work in every way. The success of the parent Society depends in a large measure on the activities of its local organizations.

While the past history of the S. A. E. shows an enviable record of great accomplishments, who can predict its future when a broader field of endeavor, made possible by the merging of allied engineering societies, is opened up to it? In the past the Society has done a great constructive work of benefit for all time to the automobile industry. With a greater membership and organization, greater funds and experience and greater recognition from the industries and Government, I predict amazing results for the coming year's work.

DISCUSSION ON CONSTITUTIONAL AMENDMENTS

PRESIDENT RUSSELL HUFF:—We have for consideration the following proposed changes in the Constitution:

"Section C-1 shall be amended by inserting therein as the name of this Society, "The Society of Automotive Engineers" with the addition of the word "Incorporated" or any other similar word indicating clearly the corporate character of the Society, if such addition shall be required by the laws of the State of New York.

Section C-29 shall be made to read:

The affairs of the Society shall be managed by a board of fifteen directors chosen from among its Members or Honorary Members,

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which shall be styled "The Council." The Council shall consist of the President, the First Vice-president and five Second Vice-presidents representing motor car, aviation, tractor, marine and stationary internal-combustion engineering respectively, six Councilors, the Treasurer and the surviving Past-president who last held office. Five members of the Council shall constitute a quorum for the transaction of business. The Secretary may take part in the deliberations of the Council, but shall not have a vote therein. The Chairman of the Finance Committee and the Chairman of the Standards Committee may attend the meetings of the Council and take part in the discussion of questions affecting their Committees, but shall not have a vote.

Section C-30 shall be made to read:

Should a vacancy occur in the Council, or in any elective office except the Presidency or First Vice-presidency, through death, resignation or other cause, the Council may elect a Member or Honorary Member of the Society to fill the vacancy until the next annual election. Should a vacancy occur in the First Vice-presidency it shall be filled by the Council designating one of the Second Vice-presidents.

Section C-35 shall be made to read:

At each Annual Meeting there shall be elected from among the Members and Honorary Members:

A President to hold office for one year.

A First Vice-president to hold office for one year.

Five Second Vice-presidents to hold office for one year.

Three Councilors, each to hold office for two years.

A Treasurer, to hold office for one year."

According to the Constitution, if twenty members favor these proposed changes at this meeting, they go to the Society for adoption on letter ballot.

R. H. COMBS:—I suggest that those of the members present who are in favor of these constitutional amendments be asked to rise.

PRESIDENT HUFF:—Are twenty or more members present who will express their views, showing whether they favor these amendments?

(Secretary Clarkson announced 59 members rising.)

PRESIDENT HUFF:—These amendments will now be submitted to the voting members of the Society by letter ballot. I will read another constitutional amendment that has been proposed.

"United Service Membership shall be composed of engineers twenty-six years of age or over, engaged exclusively by the Federal Government; the qualifications of this grade being the same as those for member. The initiation fee and annual dues for membership shall be ten dollars and five dollars respectively."

That amendment is now before the members for discussion.

R. H. COMBS:—As Chairman of the Membership Committee I

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am somewhat responsible for the proposal of that amendment. It seemed to be necessary at the time of the 1916 Summer Meeting to have some grade of membership to take care of Army and Navy officers; but since that time our affiliations with other societies, and some laws passed at Washington that have helped the Army and Navy considerably, lead me to believe that the United Service Membership would be not only unnecessary, but perhaps undesirable. I move, therefore, that the proposed new amendment be tabled.

(On motion, duly seconded, it was voted to table the proposed amendment.)

PRESIDENT HUFF:—The meeting is now open for discussion of new business.

CONSTITUTION COMMITTEE AMENDMENT

W. H. CONANT:—The Council of the Society recently appointed a committee to suggest a slight revision in the qualification clause for membership in the Constitution. As a member of that committee I discovered that the Constitution must be revised occasionally, in order that it may be brought up to date and provide for the greater activities that we undertake each year. Because of the fact that there appears to be some reason for changing, amending, adding to or enlarging its scope at nearly every semi-annual session, it has been suggested that we add to our standing committees of the Society one on the Constitution, to consider these proposals for amending it, harmonize them with other provisions of the Constitution and put them in such phraseology that they will be clear and mean what they were intended to when first proposed.

Therefore, I offer the following amendment as provided in the Constitution for proper procedure and submit it in writing to the Secretary. I move that we add to C-45 the folowing:

"There shall be also a standing committee which is to be called the Constitution Committee, consisting of three members, one of whom shall be appointed by the President each year for a term of three years. The member who shall have but one year yet to serve shall be the chairman. All proposed amendments to the Constitution shall be referred to this Committee for revision or recommendation before being submitted to the membership for consideration; and the Committee shall from time to time initiate such suggestions for constitutional changes as shall seem necessary by the activities of the society."

PROF. F. R. HUTTON:—The Society of Mechanical Engineers has found a committee of this sort essential, not only for the consideration of the wording of proposed amendments, but also that the Society should be guarded against the unnecessary taking up of its valuable time in the discussion of ill-considered amendments. When the committee reports it reports either favorably or adversely. The time of the membership is saved, because the discussion takes place in the committee and not in the general meeting.

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PRESIDENT HUFF:—Before this amendment can be discussed at length we should have a second to it. Does anybody care to second it?

PROF. F. R. HUTTON:—My speech was a speech of second.

PRESIDENT HUFF:—If there is no further discussion we will call for any other new business.

R. H. COMBS:—It has been deemed advisable to change Article C-8 of the Constitution to read as follows:

"The member grade shall be composed of persons twenty-six years of age or over who by previous technical training or experience or by present occupation are qualified to act as designers or constructors of complete automotive vehicles or their important component parts, or to exercise responsible executive supervision of the production of materials germane to the construction of automotive vehicles, or to take responsible charge of automotive engineering work, or to impart technical instruction to automotive vehicle design and construction."

The changes are these: we have eliminated the word "automobile" and substituted "automotive" on account of the proposed change in the name of the Society. We have struck out the words "or their equipment," which appeared in the paragraph regarding the construction and design of parts or equipments. We have also cancelled the words "and engineering instruction." The last three or four words in paragraph C-8, regarding instruction in the use of automobiles, have been omitted.

(On motion, duly seconded, it was voted to put the amendment before the meeting for discussion.)

SOCIETY MEMBERSHIP QUALIFICATIONS

PROF. F. R. HUTTON:—It seems to me that the amendment tends to narrow the scope of membership in the Society, or rather, not to broaden it enough. The purpose of our recent developments has been very greatly to open up and widen the significance of the membership in the Society of Automobile Engineers.

It would be desirable to rephrase the present qualification clause so that it should be so broad that a man properly qualified would have no difficulty in coming within our membership requirements.

HOWARD E. COFFIN:—The great difficulty with most engineering societies is that they are composed of men who would like to feel that they are in a class by themselves. That is one of the most disastrous attitudes as far as actual practical work is concerned. I am in favor of this organization taking such an initiative among the engineering and scientific organizations that we relegate to the background, in so far as may be possible, that feeling. This organization has a very much more difficult work to do and a very much more difficult relation with the industries which it is to serve than have any of the other so-called national engineering organizations. The history of the past two or three years proves conclusively that

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this organization has lived up to its obligations in that line. Now let us not backslide.

K. W. ZIMMERSCHIED:—It may not be sufficiently clear that this provision applies only to the designation of member grade. It does not eliminate any of the activities that we are carrying on by our membership as a whole. It is simply a very slight change in the member grade. The associate grade and junior grade stand as they always have stood. It defines the member grade a little more clearly for the help of the Council.

G. A. GREEN:—The wording as put forward now covers the situation thoroughly, but it should be broad enough to permit the admission of any man who is considered desirable. This is a society of engineers, and I think we should not forget that fact. Engineers are in a class by themselves. If we are going to have a society that is not an engineering society, then we can let into it as members those people who are not engineers.

W. H. CONANT:—I move that the following amendment be added to the proposed amendment to C-8: "Or who by reason of distinguished service or noteworthy accomplishment would in the discretion of the Council appear to be desirable additions to this grade."

(The amendment was seconded by Howard E. Coffin.)

PROF. F. R. HUTTON:—The Council has to be, in the last reduction, the gate through which every member is to come, and its discretion must be exercised. The constitution should not be so worded that any man may say, "I do come under that particular requirement as stated in the Constitution; I am therefore eligible and the Council must elect me." That view, I am sure, is not one that we desire to force on the Council; we should always leave the discretion with it.

LEGAL STATUS OF THE SOCIETY

PRESIDENT HUFF:—Before leaving the question of constitutional amendment, particularly the one changing the name of the Society, I want our attorney to tell us something about the laws in reference to these changes.

GEORGE H. ENGELHARD:—The amendment relating to the change of name of the Society affects not only its Constitution but also the charter and the certificate of incorporation. In order to make it effective, even after the Society has gone through the procedure that its constitution prescribes, through the letter ballot and all that, it will also be necessary to go through the form prescribed for the amendment of a charter. That must be done by submitting the matter to the Secretary of State at Albany, and there a law that has been enacted since this Society was formed will probably be met. That law prescribes that no corporation shall be allowed to do business in the state unless its name indicates clearly that it is an incorporated body and not merely a loose association or a partnership. In order to obey that law it would be necessary to insert the word "Incorporated," or a similar word in some form into the new name of the

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Society; and the Secretary of State would not permit the proposed change of name without some such insertion. That can be done by adding merely the letters "Inc." at the end of the name, which on the letterhead can appear in a subordinate way, so that it does not attract great attention. The law is comparatively new and has not yet been interpreted fully. We are therefore not certain whether it does apply to a society of this kind, but the chances are strong that it does. I should suggest, therefore, that in approving this amendment now for submission to the members, it be submitted in an alternative form, permitting if necessary the addition of the word "Incorporated" or any other similar word to the proposed name, so as to make it possible for the officers of the Society to put the matter through the Secretary of State's office without having to come back to the members again.

A vote has already been taken on the question whether this amendment in that form should be submitted to the members by letter ballot, and it has been decided that it should be. It might be well perhaps, on a motion to reconsider that, to propose as an amendment to this amendment an alternative form of name that the officers shall be authorized to try to put through if necessary, and that if the Secretary of State will accept the name as it was proposed this morning that then that name shall go through.

The amendment relating to the increase in the number of directors will also be an amendment to the charter and have to be put through the necessary legal formalities required by the laws relating to charters. All of this can probably be covered by proxies which can be sent out at the same time with the letter ballot, so that the members can then put the thing in such shape that the members will not have to assemble again for a live vote.

A. L. RIKER:—Does not that law simply apply to corporations that are conducted for profit? In other words, an association incorporated would be operating as an association without profit. It hardly seems necessary to have that "Incorporated" on the end of our name.

GEORGE H. ENGELHARD:—That is the precise question that in our opinion is still open. The law does not say that no corporation shall be formed and no certificate of incorporation shall be filed without the use of that word "incorporated." It says that no corporation shall be allowed to do business in this state which has not such a word or such an indication of its name. Now at first blush that might seem to let you out, because your society does not do business. Then, however, they add an express exemption from the statute which covers only benevolent and religious societies.

(On motion, duly seconded, it was voted to reconsider the vote of the meeting on the question of submitting by letter ballot the proposed amendment relating to the change of name.)

GEORGE H. ENGELHARD:—I would suggest that a motion be made that the proposed amendment of Section C-1 shall be as follows:—

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Section C-1 shall be amended by inserting therein as the name of this Society, "The Society of Automotive Engineers" with the addition of the word "Incorporated" or any similar word indicating clearly the corporate character of the Society, if such addition shall be required by the laws of the State of New York.

(On motion, duly seconded, it was voted to adopt the amendment to the proposed amendment.)

APPLICATIONS APPROVED BY THE COUNCIL SINCE JANUARY, 1917, MEETING

Members	309
Associates	424
Juniors	101
Affiliates	18
Affiliate Representatives	38
Student Enrollments	51
Total	941

June, 1917.

ELECTION OF OFFICERS

Report of Tellers

For President—	
George W. Dunham	430
For First Vice-President—	
J. G. Vincent	428
For Second Vice-President—	
C. M. Manly	431
For Members of the Council (to serve two years)—	
B. B. Bachman	429
H. L. Horning	432
C. W. McKinley	427
For Member of the Council (to serve one year)—	
F. E. Moskovics	425
For Treasurer—	
Herbert Chase	432

(Signed) FERDINAND JEHLE,
M. A. SMITH,
AUSTIN M. WOLF.

January 11, 1917.

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ATTENDANCE AT COUNCIL MEETINGS

During First Six Months of 1917

	Possible	Actual
George W. Dunham, President	6	6
Jesse G. Vincent, First Vice-President	6	3
Charles M. Manly, Second Vice-President	6	6
Herbert Chase, Treasurer	6	5
B. B. Bachman, Councilor	6	6
H. L. Horning, Councilor	6	5
C. W. McKinley, Councilor	6	4
F. E. Moskovics, Councilor	6	5
David Beecroft, Councilor	6	5
Russell Huff, Past-President	6	2
W. H. VanDervoort, Past-President	6	1
H. M. Swetland, Chairman, Finance Committee	6	1
Coker F. Clarkson, Secretary	6	5

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SOCIETY OF AUTOMOTIVE ENGINEERS, INC.

TREASURER'S REPORT

FOR THE PERIOD ENDED APRIL 30, 1917

BALANCE ON HAND, Oct. 1, 1916:

Certificate of Deposit	$22,000.00	
Checking Account	860.37	
Cash in Office	25.00	
		$22,885.37

Receipts

Initiations	$6,378.00		
Dues	29,870.80		
Pin, Binder and Folder Sales	1,363.00		
Publication and Other Receipts	31,144.88		
		$68,756.68	
Less Discount		280.83	
Total Receipts			$68,475.85
			$91,361.22

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Total Amount Brought Forward			$91,361.22
Disbursements			
Salaries	$11,062.47		
Auditing	175.00		
Pin, Binder and Folder Stock	1,106.61		
Postage	1,243.74		
Publication Expense	8,677.09		
Rent	1,747.67		
Council and Committee Expense	39.22		
Meetings Expense	11,360.03		
Telephone and Telegraph	431.62		
Carfare	5.45		
Office Expense	271.66		
Express	536.68		
Stationery and Supplies	1,083.09		
Furniture and Fixtures	1,045.90		
Standards Committee	8,460.54		
Convention Reporting	203.68		
Library Expense	34.03		
Investment	14,591.95		
Unclassified	5,558.82		
		$67,635.25	
Less Discount		325.76	
Total Disbursements			$67,309.49
			$24,051.73

BALANCE ON HAND, April 30, 1917:

Certificate of Deposit	$13,000.00	
Savings Bank	7,000.00	
Checking Account	3,696.73	
Cash in Office	355.00	
		$24,051.73

I hereby certify that the above statement is correct.

H. D. DABNEY,
Public Accountant.

May 17, 1917.

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SOME PROBLEMS IN AIRPLANE CONSTRUCTION

By Capt. V. E. Clark, Capt. T. F. Dodd, and O. E. Strahlmann

(Member of Society) (Non-Member) (Member of Society)

Abstract

The authors advance for discussion some important problems in the construction of airplanes for military use in this country. The functions of military airplanes designed for strategical and tactical reconnaissance, control of artillery fire and for pursuit are outlined.

Problems in construction with reference to the two-propeller system, methods of reducing vibration, application of starting motors, details of the gasoline supply-system, metal construction for airplanes, flexible piping, desirable characteristics of mufflers, shock absorbers, landing gear, fire safety-devices, control of cooling-water temperature, variable camber wings, variable pitch propellers and propeller stresses, are all given consideration.

The paper is concluded with suggestions for improvement in design relating to the use of bearing shims, the rigidity of crankcase castings, interchangeability of parts and better detail construction in the oiling, ignition, fuel supply and cooling systems.

In this paper we shall advance for discussion, with hopes of solution, some important problems connected with the construction of airplanes intended for military uses in the United States. Many of these problems also apply to airplanes built for commercial and sporting purposes. Although the lessons on type development that are being learned in the European war are of immense value to us, many conditions that we must meet are peculiar to this country.

MILITARY FUNCTIONS OF AIRPLANES

We will first consider the various military functions (becoming more and more distinct), as we understand them at present. It must be borne in mind that other important uses will, in all likelihood, develop. The airplane itself and its uses in war are so new that it is impossible to predict, with any degree of accuracy, the developments in even a few months. At present the airplane is being used in war for reconnaissance, fire control, rapid transportation of important officers or communications, demolition of valuable structures by bombing, and to attack hostile airplanes in order to prevent them from performing these functions.

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1a—Strategical-Reconnaissance Machines

For this work the fuel capacity should insure a flight of at least 500 miles without stop. The average speed during this flight should not be less than 80 m.p.h. The *military load* consists of one pilot, one observer, a sketching outfit, a camera, a wireless set, and navigating instruments.

The general rule is becoming more and more firmly established that no military airplane should be entirely defenseless against the attack of hostile airplanes.

This and all other service types should carry one or more machine guns, and the general arrangement of the system should be such as to permit extensive fields of fire in important directions.

The useful load, that is, fuel plus the *military load*, and the speed range, determine the power required. A powerplant of about 200 hp. would apparently satisfy most economically this problem, the primary requirements of the powerplant being reliability and fuel efficiency.

Assuming this, the fuel will weigh between 700 and 800 lb. The military load will be almost 600 lb. The complete airplane, fully loaded, will weigh over 3500 lb.

This airplane would also be adapted for long-distance transportation of important communications or officers.

1b—Tactical-Reconnaissance Machines

The fuel capacity of this type should insure a continuous flight of at least 250 miles at a speed of not less than 85 m.p.h. The military load should be about the same as that carried in the strategical-reconnaissance machine.

A powerplant of about 125 hp. is desired, the primary requirement being reliability. The fuel will weigh about 225 lb., the airplane loaded, somewhat less than 2400 lb.

2—Field-Artillery Fire-Control

The tactical-reconnaissance machine can perhaps perform this duty, but it appears that the fire-control machine should be slower, and that one of its primary requirements should be an extremely good field of vision. The engine should be of 125 hp., or perhaps less.

3—Long-Ranger Bombers

We here attack a more difficult problem, owing to the heavy useful load with which we must climb from the starting field.

There will probably be a wide range in sizes of machines intended for this duty. We will discuss what we might call an average type at the present time.

The fuel capacity should permit going out at least 200 miles and returning safely, starting with a load of bombs weighing, say, 400 lb.

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The machine should be capable of defending itself from hostile aircraft, so that it can operate independently of escort.

It appears that we need at least 250 hp. and that, depending upon the total useful load, 300 hp., or even 350, would not be too great.

If we assume 300 hp., the fuel weight will be at least 900 lb. and the total military load, including bombs, about the same.

This airplane will weigh, loaded, between 5000 and 6000 lb.

4—Pursuit Machines

The function of this type is to attack and drive off hostile airplanes of any of the three first-mentioned types, preventing them from accomplishing their purpose. In fact, the employment of this type should afford a sort of offensive defense against hostile aircraft of all descriptions.

While the types 1a, 1b, 2 and 3 are interested primarily in objects *on the ground*, the pursuit type is occupied solely with events *in the air*. This type is at present divided into the one- and two-place subclasses.

a.—*One-Place Machine.* This carries fuel for two hours at full speed, about 130 m.p.h. The pilot, the only occupant, controls the machine and operates the machine gun, or guns, of which there can be from one to four. He usually aims the gun, in action, by "pointing" his airplane.

All characteristics are sacrificed, within reasonable limits, in order to obtain rapid climbing ability, high speed, rapid climbing ability *at* high speed, and the greatest possible dodging ability, or "handiness."

In the engine, reliability must be sacrificed to a great extent to obtain low weight per horsepower, in order that the necessary attributes of the airplane can be obtained. Between 90 and 130 hp. is desired. At present by far the greatest percentage of engines in this type of machine are of the rotary air-cooled type.

b.—*Two-Place Machine.* This carries fuel for three hours at full speed, about 110 m.p.h. Space is provided for two men, the pilot and the gun operator. This is, of course, somewhat larger and less agile than the one-place machine and, it is believed, is rapidly losing its popularity in favor of the smaller type. The power required is from 110 to 160 hp.

5—*Oversea Reconnaissance*

a.—The long-range machine of this type must carry fuel for six hours at not less than 75 m.p.h. Two men, wireless-transmitting set and navigating instruments are carried. The 300-hp. plant used on the bomber should answer for this type satisfactorily, the greatest requirements being reliability and fuel efficiency.

b.—The machine used for short-range reconnaissance and coast-artillery fire-control must carry fuel for three to four hours at speed of not less than 75 m.p.h. Two men, navigating instruments, wire-

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less and other signalling apparatus will be required. The 200-hp. engine used in the land strategical-reconnaissance machine should answer.

SOME PROBLEMS IN CONSTRUCTION

It is important that engineers work out the mechanical details of a great many problems in construction, among which are the two-propeller system, the reduction of vibration, the development of light engine starters, gasoline supply systems, devices required for safe landing and improvements in wing and propeller design.

The Two-Propeller System

When an all-round field of fire is necessary, the best arrangement is to carry the two or three operators and the main supply of gasoline in a central body, and to drive the machine by two propellers—one at each side of this central body.

By such an arrangement machine guns can be fired forward, in attack, and to the rear, in retreat, with extensive fields of fire in both directions, above and below, to right and to left. This attribute is always desirable, and, in some types, as for instance in the bombers and reconnaissance machines, is essential.

These propellers can be either tractor screws or "pushers." The left-hand propeller should turn clockwise and the right-hand propeller counter-clockwise. This symmetrical arrangement is a great advantage, in that it permits equalized torque and gyroscopic effects when turning in different directions. In addition, it makes for safety, because the downward velocity imparted to the inboard parts of the two slip-streams that strike the horizontal tail-surfaces produces an inherent tendency toward nose heaviness without power and toward tail heaviness with power. We can, therefore, design so that the line of thrust is considerably above the center of gravity, compensating for this, and obtaining another convenient feature.

A fourth great advantage of such a system is the fact that great power can be transmitted with good propeller efficiency without demanding excessive diameter and retaining satisfactory structural factors of safety. It is highly desirable that the line of thrust of the propeller be kept below the center of gravity of the airplane, unless the two-propeller arrangement, as described above, be used; a propeller of large diameter, with sufficient clearance, necessitates a high landing gear with its many great disadvantages. It appears extremely difficult to build a propeller of wood, of satisfactory strength (if the speed of revolution be high), giving good efficiency, to transmit more than 160 hp. Peculiarly stringent climatic conditions making for rapid deterioration have increased this difficulty. In fact the tendency to reduce cylinder diameter and increase crankshaft revolution speed is already necessitating a gear between crankshaft and propeller-shaft in order to keep the propeller speed below 1300 r.p.m., which is considered desirable.

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A fifth advantage of the two-propeller arrangement is that the total resistance of the air to progress through it of the complete airplane while flying under power will be diminished owing to the fact that less total projected area of bodies will lie in the propeller slipstreams. The velocity of the air striking objects lying in the slip stream is, say, 20 per cent higher than the velocity of air not in the slip stream. The resistance varies about as the square of the velocity. Therefore, all other things being equal, less power will be required to overcome the total resistance.

Arrangements with Two Propellers

Four different systems for two-propeller installation have been suggested:

1. Two engines, one on each side, mounted out on the wings. The fundamental weakness of this system is that these great masses, removed so far from the center of gravity of the airplane, produce great moments of inertia, and consequently show periods of oscillation. The machine is "logy" and probably not satisfactory for any but "hydro" purposes, in which case a "snappy" machine is impossible at best.

2. Two engines mounted in the central body between pilot and observer, each driving its own propeller through bevel gears and shafts, or by other method, the two systems being independent.

3. One large engine, mounted in the central body, driving both propellers, one propeller at each side.

4. Two engines, mounted in the central body, with a system of clutches connected with the transmission system in such a manner that either engine, or both engines, can drive both propellers, it being possible for the pilot to shift during flight.

The last system presents many advantages over the others, but it is entirely possible that excessive weight and complexity will render it impracticable. The system, as a whole, *must be reliable.*

In the design of any system of transmission for the two-propeller arrangement, the engineer must bear in mind that the structure of the wings supporting the propeller and transmission is very light and rather flexible, usually vibrating during flight.

The information at hand indicates that, to date, no successful airplane of the two-propeller type has been developed, but it is urged that the possible advantages are such as to warrant great effort on the part of engineers in developing this improvement.

Methods of Reducing Vibration

The problem of reducing vibration of the airplane in flight, initiated by the engine, is a serious one. It is difficult to realize, without actual experience, the viciousness of this vibration, especially when the engine is of the eight-cylinder type, even though it is running normally. After one experiences this vibration, it is easy to understand why ignition systems, gasoline-supply joints, water-cooling

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systems, delicate instruments, and even wire terminals and structural joints of the airplane itself, deteriorate so rapidly.

The vibration throughout the airplane can of course be reduced by better design of the engine mounting, but we cannot hope to eliminate it entirely in this manner, if the engine itself is not of the proper design. We must remember, in this connection, that the engine is not always operating at the same speed during flight. We can, for instance, if flying at extremely high speed, turn the crankshaft over at, say 2000 r.p.m.; whereas, if our sole object is to remain in the air without losing altitude, as when spotting for artillery fire, we can use a crankshaft speed of, say, not more than 1200 r.p.m. The vibration at any speed should not be excessive.

Starting Motor for Engines

The development of light starters is a matter of immediate importance. For instance, a seaplane equipped with two engines, one out on each wing, would be utterly useless without reliable starters. It seems quite probable that electric starters will be preferable, if the weight can be reduced sufficiently, and if the danger of spilling electrolyte be eliminated. It appears that any engine of over 140 hp. requires a starter.

Reliable provision for starting the engine in extremely cold weather is necessary.

Gasoline Supply-System

To date none of our pilots are anxious to fly across country with any except gravity feed.

The gasoline supply-system, Figs. 1 and 2, required by the U. S. Army for twin-engine seaplanes, is as follows:

The flow of fuel shall be from the main supply tank in central body to the gravity service-tank located at the center of the upper wing; from gravity service-tank by gravity, along the lower wing panels, to the small headers at the carbureters of the two engines, and from the small headers in each case to the carbureter.

These tanks shall have fuel capacities sufficient for operation at full rated power, as follows: Main supply tank, 4 hr. 35 min.; gravity service-tank, 25 min.; each header to carbureter, 1 min.

The design and material of the gasoline supply-system throughout shall be such as to obtain extreme lightness as far as consistent with strength and resistance to corrosion.

Main Gasoline-Supply Tank in Central Body

This shall be divided by one vertical longitudinal bulkhead and one vertical transverse bulkhead into four gasoline-tight compartments. Proper swash-baffle plates shall be installed. The tank shall be of sturdy construction throughout.

The main tank shall be of such shape as to properly fit the central body. It shall be securely fastened in the structure of the central body in such a way as to be undisturbed by any possible motion of the airplane. The structure shall be such that the tank will withstand an internal pressure of at least 7 lb. per sq. in. without leakage of gasoline. The design shall be such that there will be no ill effects from drumhead vibration.

Suitable means shall be provided for quickly and conveniently filling and for completely draining all four compartments.

Each filling hole shall have a suitable screen filter, 100 mesh to the inch.

Plugs or caps for filling holes shall be air-tight and provision shall be made for "safetying" them positively in place. Suitable gaskets shall be used.

Provision for reducing to a minimum the rate of leakage due to bullet holes by lining the inside of the tank with a special material, is highly desirable.

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Suitable gasoline-supply gage shall be installed.

There shall be leads from the bottoms of the four compartments to the upper gravity service-tank.

Supply of Gasoline from Main to Gravity-Service Tank

This shall be by two methods:

First.—Air-fan driven pump, so designed as to maintain proper air pressure in or suction from the main tank system, and to operate satisfactorily during flight. An alternative and better method will be to install two such fans, each fan maintaining pressure in any two of the four compart-

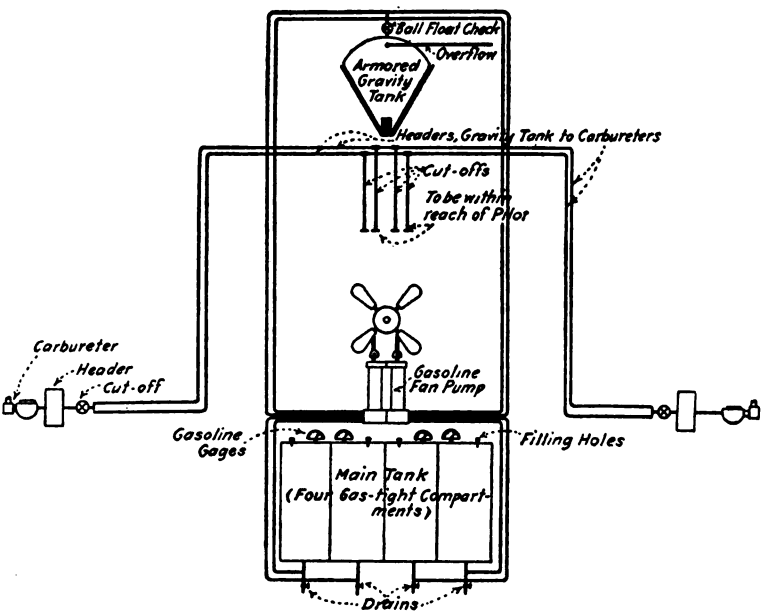

FIG. 1—GASOLINE SUPPLY SYSTEM (SUCTION PUMP) FOR MILITARY SEAPLANE

ments of the main tank. When any one or two of the four compartments of the main tank leaks (because of bullet hole or through other cause), an arrangement by which pressure or suction can be maintained through the leads from the tight compartments is highly desirable.

Second.—A hand air-pressure pump in or at the side of the pilot's cockpit, which can be used when not in flight or in an emergency. This pump shall be located in the cockpit at a point as high as will permit convenient operation by the pilot in his seat. It shall be provided with a suitable air-pressure gage, visible to the pilot. Its connections with the compartments of the main tank shall be at a point as high as practicable to prevent the pump becoming flooded with gasoline. An arrangement by which pressure can be maintained by the hand air-pressure pump on tight compartments of the main tank when one or two compartments leak is highly desirable.

Construction of Gravity Service-Tank

This tank shall be of sturdy construction, securely supported in place, and provided with the proper number of swash-baffle plates. It is considered desirable to protect this tank with light V-shaped armor on the under side. An automatic ball-float valve shall be provided to prevent overfilling of this tank. A suitable overflow pipe out of the top center of the gravity service-tank shall be provided. The gravity service-tank shall be of good stream-line form.

A suitable gage, visible to the pilot in his seat, shall be in the gravity service-tank. This gage shall be connected at such a point that it will register accurately through the range of normal flight attitudes.

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From the gravity service-tank the gasoline shall be led to a small header at each engine by leads within or along the lower wing panels. Between gravity service-tank and each header shall be two independent, and, as far as practicable, isolated tube leads. Each of these four leads shall connect with the lower part of the gravity service-tank at such a point that the supply will not be interrupted at any normal flight attitude.

At the connection of lead to the gravity service-tank shall be a suitable wire gauze strainer, mesh 100 to the inch. Provision shall be made to prevent the possibility of air pockets in the gasoline leads from the gravity service-

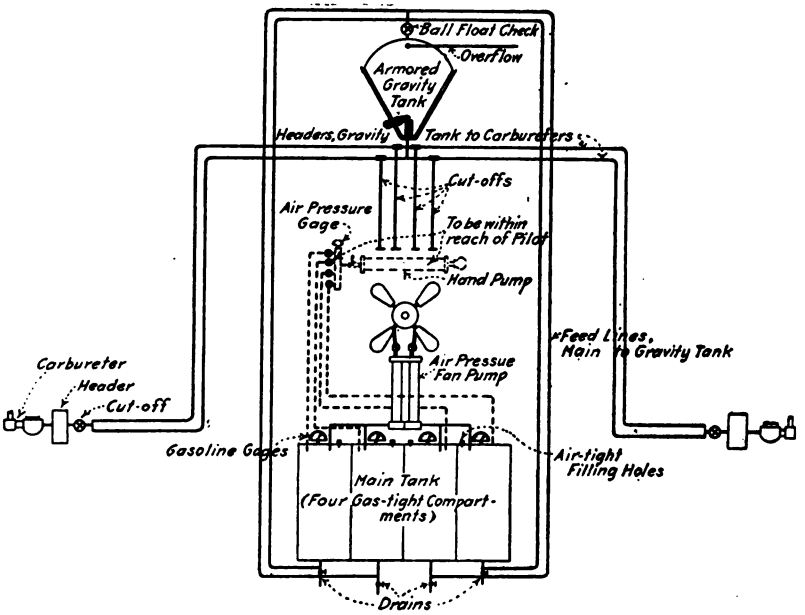

FIG. 2—GASOLINE SUPPLY SYSTEM (AIR PRESSURE) FOR MILITARY SEAPLANE

tank. Provision shall be made for permitting the pilot, while in his seat, to cut off the gasoline supply, through all leads, from the gravity service-tank to the carbureter headers.

Headers Between Carbureter and Service-Tank

A small cylindrical or stream-line tank or header shall be installed in the immediate vicinity of each carbureter. The gasoline shall pass through this header after coming from the gravity service-tank.

Its capacity shall be sufficient for one minute's running at full-rated horse-power. The central portion of this header shall be on a level with the jets of the carbureter. The axis of the cylinder shall be vertical.

The cylinder shall be of sufficient length to give satisfactory head, either when the airplane is in normal attitudes or when it is upside down.

Provision shall be made to prevent gasoline from backing up into the service lead instead of coming into the carbureter when the engine is upside down.

Suitable gasoline cutoff shall be installed near this header in such a position as to be convenient for operation to a man standing on the ground or on the wing.

Tubing for Fuel Leads

At every point these shall be of the highest grade material best suited for the purpose. It shall be approved by the inspection department. Flexible tubing shall be 5/16-in. No. 2 copper tubing. Non-flexible leads shall be piping as approved by the inspection department.

Tubing shall in all cases be of diameter sufficient to give free and con-

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tinuous flow under severe vibratory conditions. In the absence of other instructions the bore shall be 5/16 in.

All tubing shall bo securely fastened in such a way as to resist wear, vibration, and chafing. The number of joints and fittings shall be reduced to a minimum.

Unions, ells, tees, and fittings, to be S. A. E. Standard, approved by the inspection department. The method of connecting all leads shall be approved by the inspection department. All fittings shall be readily accessible for inspection, adjustment, repair, or removal.

Considerable ingenuity will be required to work out satisfactorily the mechanical details of this complicated arrangement. For instance, a satisfactory method is required of insuring feed from the compartments of the main tank, up to the gravity tank, when one or more of the main compartments are punctured by shot.

Metal Construction for Airplanes

It is suggested that there is a considerable field for development of airplane structures made of steel or aluminum alloy. The authors have gone briefly through the layout of an airplane in which every strength member is of metal. In this design it was found most convenient to use seamless steel tube at some places, welded tube at others, channel section at others, I-section and L-section, at others. At a few points aluminum alloy was used, at other points pure aluminum, assumption being made that this aluminum was *rolled* in such a way as to give it certain desired physical characteristics.

It is suggested that, even with the present standard method of construction, there is great room for improvement in the material and method of heat treatment of the metal fittings used in conjunction with wood and wire. Especially where fittings are bent both with and across the grain, a special alloy appears advisable. The same holds for fittings shaped by die-forging. Chrome vanadium steel, to comply with S. A. E. Specification 6130, and heat treated in such a way as to render it best in each case, is suggested. It is believed that the total weight of an airplane can be materially decreased, without sacrifice of strength, and hence superior performance obtained, by the use of better steel.

The construction of floats of metal for seaplanes appears to be a possibility as is also the use of metal for airplane propellers. It is possible that the entire body might be made of light pressed steel, or aluminum, with holes to decrease the weight cut at proper places, and covered with linen.

Flexible Piping

A satisfactory flexible gasoline lead has not yet been developed. Such a lead should resist the action of vibration, should be light in weight and resist cutting or denting. The method of making joints is important. The duct should be carefully sweated into proper terminal fittings. Tube ends of fittings should have spiral springs wound around them for at least 2½ in., thus preventing sharp bends and distributing the effects of vibration. All unions should be

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ground, with spherical seats, and threads should be cut clear and sharp, with all burrs removed. The inside diameter of tube should not be less than 0.35 in.

A *flexible* pipe, light in weight, of material suitable for leading the *exhaust* away from the engine would be useful.

Muffler Requirements

In military service a hostile airplane is usually first discovered by hearing it. A muffler satisfactory as to low weight, flexibility, loss of power through back pressure, durability against corrosion, and efficiency as a muffler, is highly desirable.

Shock Absorbers for Landing Gear

Rubber is not satisfactory as a shock absorber for heavy airplanes. Neither is it satisfactory as a military supply, especially when it is subjected to the action of heat and the direct rays of the sun.

It seems necessary to develop a steel-spring shock-absorber. The action of this steel spring must, however, be damped by an oil cylinder. Without this damping the action is such as to cause the airplane to bound excessively upon striking the ground.

Brakes Required When Landing

The development of a brake to reduce the run of the airplane after it has touched the ground, thus permitting it to land in restricted areas, appears to be a difficult problem. It is a moot question whether such a brake is desirable when the simple two-wheel landing gear is used, as its action has a tendency to throw the airplane over on its nose. Where more than two wheels are used, however, a brake fitted to the two main rear outside wheels in such a way that the pilot can, from his seat, operate either brake, or both brakes together, would be desirable. Such an arrangement would permit him not only to stop his machine quickly, but also to steer it on the ground to some extent.

Folding Landing Gear

The development of a landing gear that can be submerged within the body by the pilot, during flight, would materially increase the speed of the airplane by reducing the "parasite" resistance. Such a mechanism should be light in weight, sturdy and simple.

Gasoline Supply Gage

The development of a gage to indicate the supply of gasoline remaining in the tanks to the pilot, whose seat can be out of view of the tanks, is necessary. Such a gage should be simple and sturdy. The accuracy and reliability with which it registers should not be affected by any change in altitude of the airplane. It should not form a possible source of leakage. It should be adapted to both the pressure and suction systems of feed.

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Fire Safety-Device

Many casualties have occurred because airplanes have caught fire in the air. While it has been impossible to determine from the wreck just what led to the fire, it is quite probable that many of these accidents were due to back fire into the carbureter that forced burning gasoline out into the surrounding structure, or to a leaking gasoline tank. The development of a device that will render such an accident impossible would save many lives.

In this connection it should always be a rule for airplane constructors never to have any electric lead near a gasoline supply or lead.

Altitude Adjustment for Carbureter

The development of a device to regulate automatically the mixture for variations in density of air incident to changes in altitude, would be valuable.

Device for Firing Machine Gun

A system by which machine guns would be fired by positive action of one of the engine shafts is necessary on a single tractor-screw machine on which it is proposed to fire through the disk of the propeller. The most convenient way would probably be to fire from a camshaft, as it is believed that fire at the rate of 600 per minute is the reasonable limit. The firing pin on the gun should strike the primer at the instant that the rear edge of the blade passes the line of fire of the gun. The propeller should be two-bladed for this work. Such a device should be simple, durable and reliable.

Vibration-Absorbing Material

The development of a material more suitable than ordinary felt for padding the points of support of radiators, and the like, is highly desirable.

Adjustment of Radiator Cooling

A more suitable method of permitting the pilot to adjust the amount of cooling done by the radiator in order to compensate for changes in temperature of air, or changes in speed through the air, is necessary. Such arrangement should permit operation by the pilot from his seat during flight, or, better yet, might be automatic; the device being operated as a function of the temperature of the water. It should be durable and should act with reliability.

Variable-Camber Wing

Great speed range is a desirable attribute of an airplane, as it permits high speed of travel in the air and yet low speed while landing, which of course makes for safety if the landing place be small or rough. Great improvement in the speed range can be brought

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about by use of a variable-camber wing surface, that is to say, if the section form of the aerofoil could be changed at will during flight from a shape such as *A* to one similar to *B*, Fig. 3.

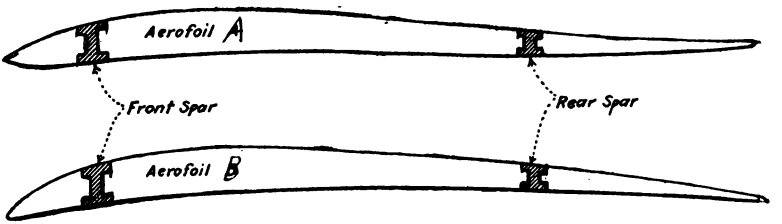

FIG. 3—FORMS OF VARIABLE AEROFOIL SECTIONS

An aerofoil such as *B* has a high lift-coefficient at large angles of attack (the angle of attack being the angle between the chord tangent to the lower surface and the relative wind). At small angles of attack, where the lift coefficient is low, this shape has a relatively high resistance and will consequently require a great power to drive it through the air at speed high enough for the necessary support.

The reverse is true of such a shape as *A*, which, though the lift coefficient is poor, has an appreciably lower resistance or "drag."

If, then, we could utilize the section *B* for slow speed, as in making landings, and section *A* for high speed, the safe limits of speed between which the airplane could fly would be extended. The variable-camber would permit changing the characteristics of the wing to suit conditions.

Performance curves (Figs. 4 and 5) have been worked out for a pursuit machine having a good aerofoil (fixed-camber) in common use to-day; and a similar series of curves for a machine with an assumed variable-camber wing. It has been assumed that otherwise both airplanes are similar. No allowance has been made for the probable increase in weight of the variable-camber machine due to the operating mechanism and structure.

The slow speed of the fixed-cambered wing airplane is 61 m.p.h. This will only permit landing the airplane on an ideal field by a very skilful pilot.

On the other hand the variable-cambered wing airplane can be flown at a slow speed of 56 m.p.h.

The curves show that with the variable camber a higher speed, 127 m.p.h., as against 120 for the fixed camber, can be obtained with the same power. The same speed might be obtained with less power.

If the same high speed were desired the variable-camber wing might have a greater area. It would then have a *slow speed of 46*

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m.p.h. as against 61 for the fixed camber (allowing for increased weight due to added surface), which would permit its being flown and being landed in an ordinary field, by the ordinarily skilful pilot.

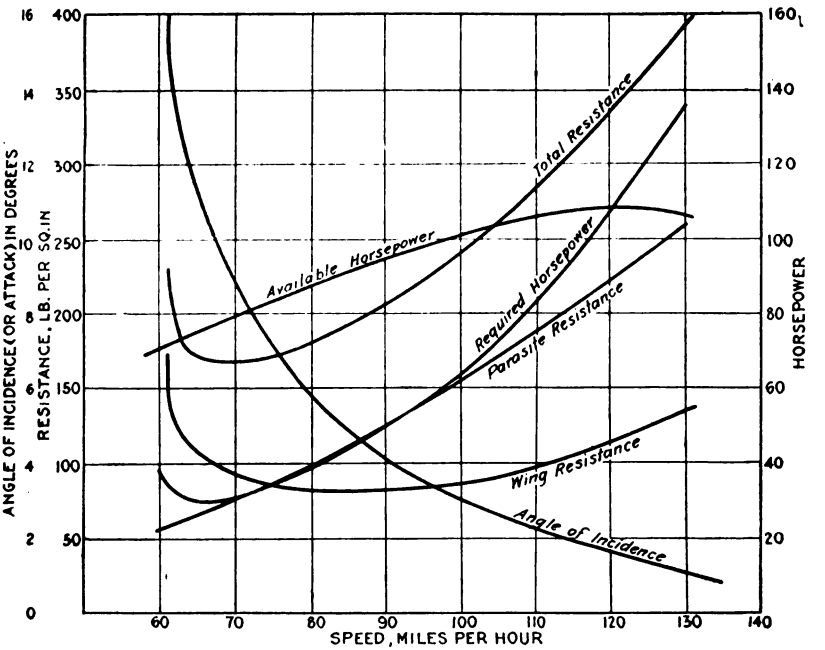

FIG. 4—PERFORMANCE CURVES FOR AIRPLANE WITH FIXED-CAMBER WING

It can, therefore, be seen that the invention of a suitable variable-cambered wing would be a big step in advance.

APPENDIX GIVING MATHEMATICAL CALCULATIONS

In calculating the values used in plotting the performance curves, Figs. 4 and 5, the weight of machine was assumed as 1150 lb., and the engine was assumed to develop 140 b.hp.

The lifting power of a wing is given by $L = K_y A V^2$, where L is the lift, K_y the lift coefficient (which varies for different attitudes of the wing to the relative wind and must be determined by experiment), A is the area of the wings and V the air speed.

Similarly the resistance of a wing is expressed by $D = K_x A V^2$, K_x being a variable coefficient that must be found by experiment.

The speed at which the airplane must fly for any assumed angle of attack can be found from the lift formula. The lift in all cases, of course, is assumed to be the weight of the airplane.

The resistance of the wings at these speeds can then be determined and the total resistance found by adding the parasite resistance, that is, the resistance of the body, landing gear, etc.

From the total resistance the horsepower required can be calculated and plotted against speed. The horsepower available is obtained by multiplying the efficiency of the propeller by the brake horsepower delivered by the engine.

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The ribs ordinarily used in the present type of wing construction are shown in Fig. 6. The weight of such a rib for a small pursuit machine, as assumed in the above calculations, would be less

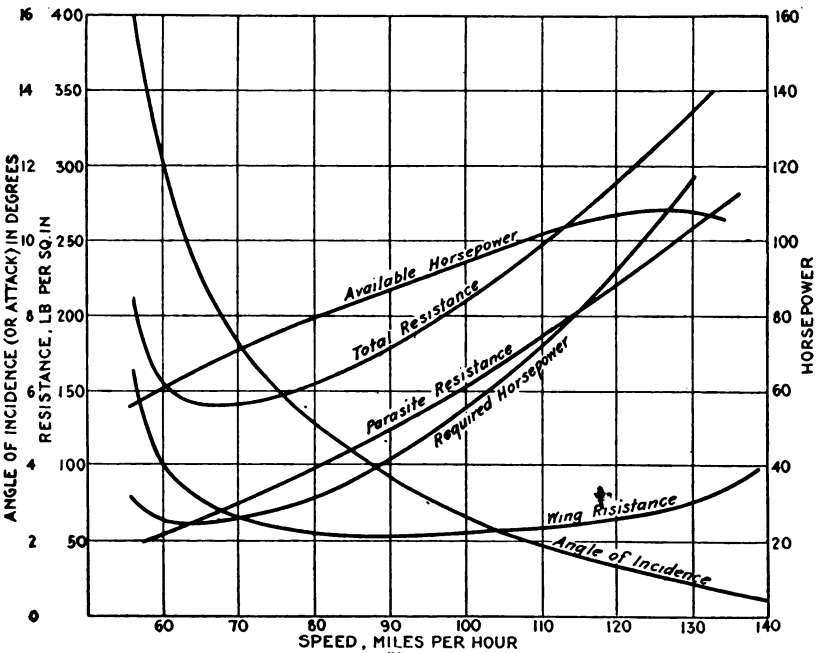

FIG. 5—PERFORMANCE CURVES FOR AIRPLANE WITH VARIABLE-CAMBER WING

than ½ lb. The ribs would be spaced from 12 to 15 in. along the spars. A wing complete with cover, internal bracing, etc., weighs from 0.6 to 0.7 lb. per sq. ft. of surface.

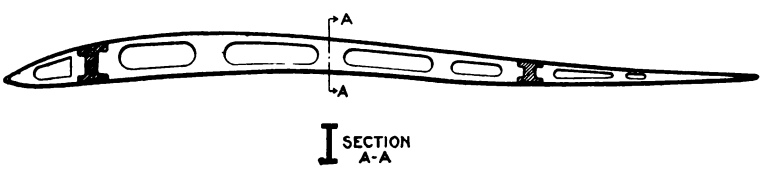

FIG. 6—RIB USED IN PRESENT TYPE OF WING CONSTRUCTION

Propellers with Variable-Pitch Angle

Improved performance of an airplane, especially as regards radius of action, can be brought about by means of a propeller whose pitch

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angle can be varied by the pilot while in flight. The liability of failure, the complexity of the mechanism and the weight added, must be weighed against the gain obtained in the performance.

The gain in efficiency of the variable-pitch propeller over the

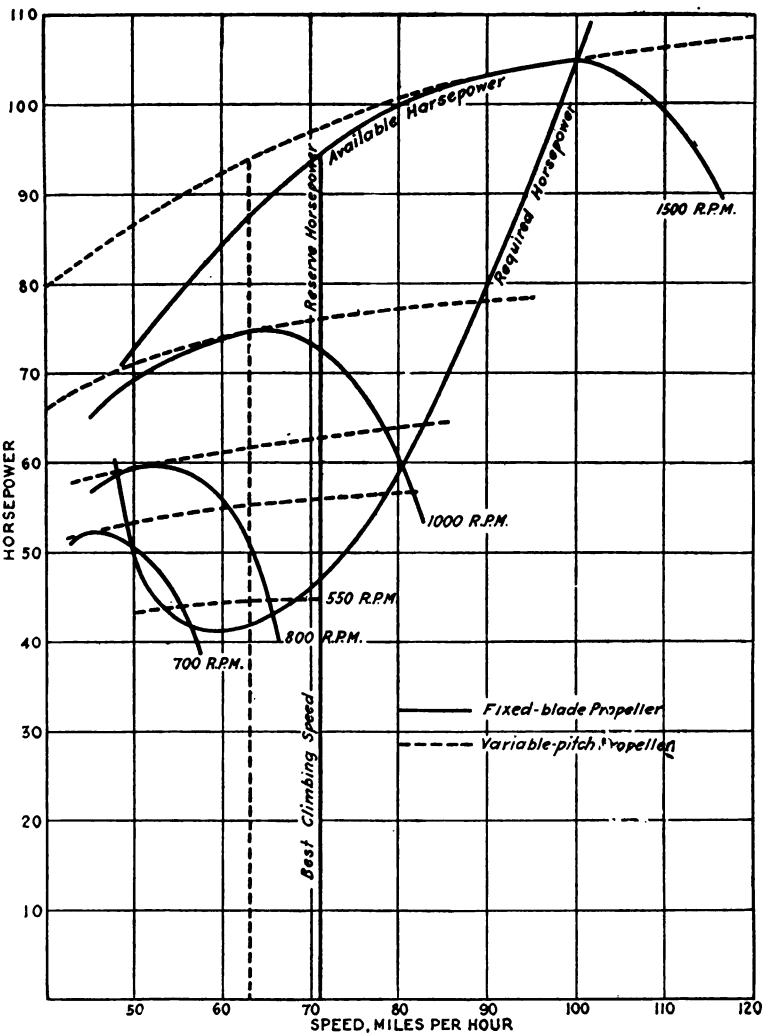

FIG. 7—PERFORMANCE CURVES FOR RECONNAISSANCE TYPE OF AIRPLANE WITH FIXED-BLADE AND VARIABLE-PITCH PROPELLER

fixed-blade type is considerable. This increased efficiency makes available more horsepower for climbing, giving faster climbing, and permits throttling down to attain the economical speed, and hence in-

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creases the flight radius and the time in the air with a given quantity of fuel.

These facts are more clearly brought out by the approximate curves given in Fig. 7, which give the horsepower required, and horsepower

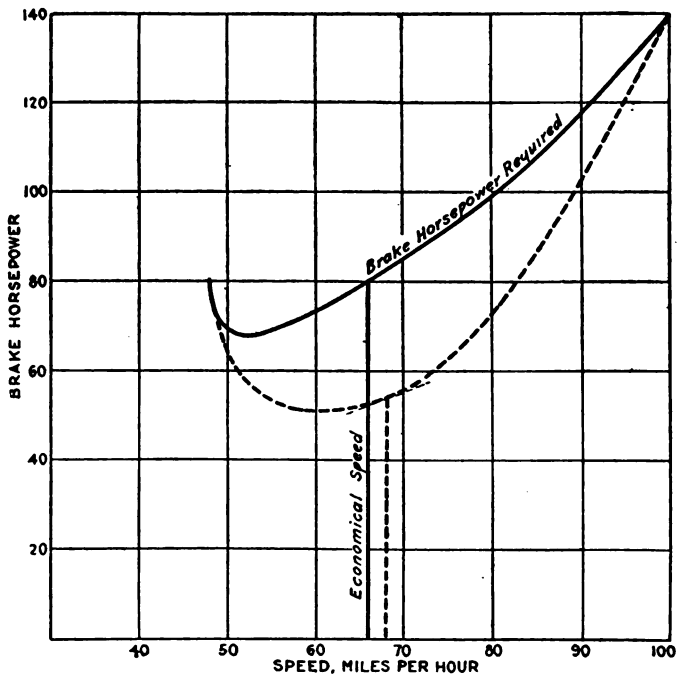

FIG. 8—SHOWING ECONOMICAL SPEEDS OF AIRPLANES WITH FIXED-BLADE (FULL LINES) AND VARIABLE-PITCH (DOTTED LINES) PROPELLERS

available at various speeds for a fast reconnaissance type of airplane of refined design. The full lines give the power available for a fixed-blade propeller; the dotted lines for a variable-pitch blade. It is assumed that the propeller was designed for maximum efficiency at the high speed of the airplane.

The most evident gain made by using the variable pitch as observed from the curves is the increased reserve horsepower available for climbing. This particular assumed airplane, with full load, climbs:

With fixed-blade propeller: 650 ft. the first minute.

With variable-pitch propeller: 715 ft. the first minute.

The increase in the radius of action is very great, the greatest radius of action being obtained when flying at the economical speed of the airplane. Fig. 8 shows the economical speed in each case.

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On one filling of the gasoline tanks the fixed blade would carry the machine about 690 miles in 10½ hours. The variable-pitch blade would carry the same machine a distance of about 1050 miles in 15½ hours. (Were this machine driven at full power it could go but 600 miles with either propeller.)

These curves, while only approximate, will at least give some indication as to the value of a variable-pitch propeller, especially when great distances are to be covered.

The greater efficiency of the variable pitch would be of value in giving increased climbing ability at high altitudes and would make possible the reaching of greater heights with a given machine.

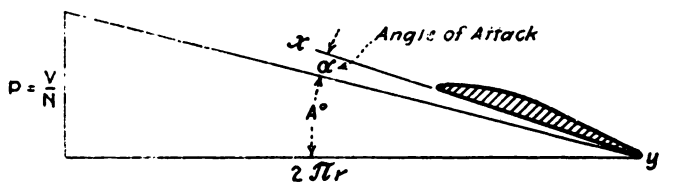

FIG. 9—DIAGRAM SHOWING EFFECTIVE PITCH OF PROPELLER

Another feature possible, of secondary importance, in a variable-pitch blade is that it can be rotated to give a large negative angle of attack, or possibly reversed, when the airplane is on the ground making a landing, thus serving as a brake and cutting down the distance the machine rolls on the ground.

APPENDIX GIVING MATHEMATICAL CALCULATIONS

The weight of assumed airplane fully loaded is 2400 lb. The brake horsepower of engine is as given in Fig. 11. The fuel capacity is six hours at full power.

If A denotes the angle that the helix line makes with the base line, Fig. 9, V the translational velocity in feet per second and N the propeller speed in revolutions per second, then the distance advanced each revolution, neglecting slip, is $(V \div N)$ ft., which is the effective pitch of the propeller.

Suppose the chord XY of the blade section at any radius V, makes an angle α with the helix line, Fig. 9. Angle α is called the angle of attack of the section. As $(V \div N)$ changes owing to a variation in either V or N, or in both, the blade section will have a varying angle of attack, an increase in $(V \div N)$ decreasing the angle of attack and vice versa.

The efficiency of such an element is expressed by

$$e = \frac{\tan A}{\tan (A + G)}$$

where G is the gliding angle, which is a function of the angle of attack and varies with the type of section employed. With the usual section used in propeller design G is a minimum when the angle of attack is about 4 deg. It would therefore be advantageous from the viewpoint of efficiency of the section to keep the angle of attack at 4 deg. throughout the speed range of the airplane.

This can be accomplished by means of a flexible blade whose pitch angles could be changed a varying amount from the tip of the blade to the root or hub section. Such a blade is out of the question in the light of present day practice. A good approximation to such a blade could be more simply had by rotating the blade about its axis perpendicular to the shaft. With the usual type of section employed the approximation is good as the value of G does not change greatly for a degree or so on either side of the best angle of at-

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tack. A mean value for the angle of attack could therefore be found giving practically the same efficiency as though all the sections were at the best angle of attack.

Fig. 10 shows curves in which efficiency of a propeller is plotted against $(V \div N)$. The full line gives the efficiency for a fixed blade, the dotted line

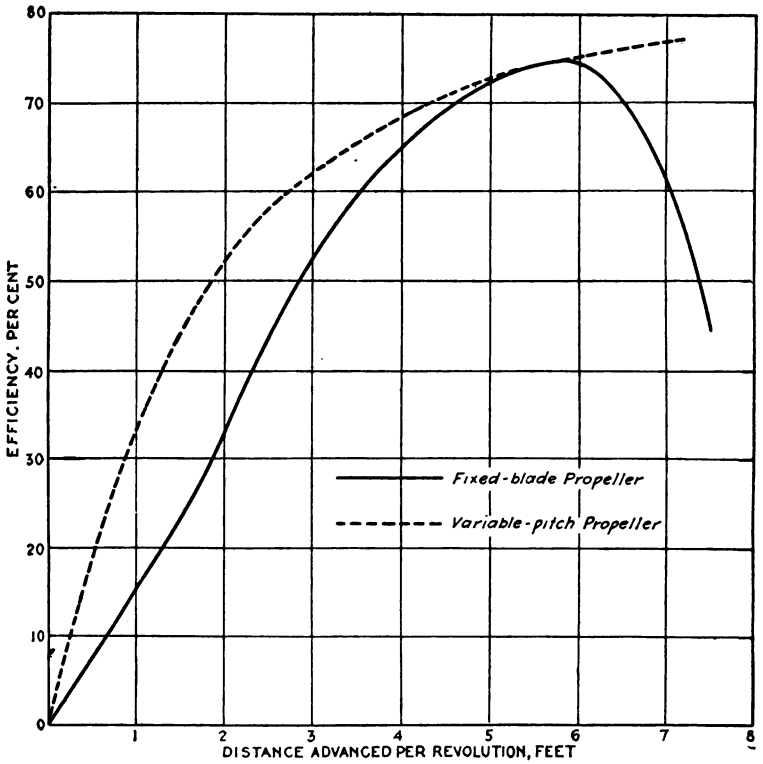

FIG. 10—RELATION OF PROPELLER EFFICIENCY AND EFFECTIVE PITCH

the efficiency of the same blade were the angle of attack kept at approximately 4 deg. It is assumed that the fixed-blade propeller was designed for a maximum efficiency at a value of $(V \div N)$ of about 6 ft.

PROPELLER STRESSES

In connection with the subject of propellers, it may be of interest to give a brief review of the variation of stress that occurs in a propeller blade under an assumed condition of flight.

The blades of a propeller are subject to the following stresses when an airplane is in any but a straight-line flight:

1. *Shear* due to aerodynamical forces.
2. *Torsion* due to the distance between the center of gravity of the blade section and the point of application of the resultant of the air reactions.
3. *Tension* due to centrifugal force.

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4. *Steady bending* due to aerodynamic forces; torque and thrust imposing a distributed load on the blade, the hub being the fixed point of support.

5. *Reverse bending* due to gyroscopic forces, which occur only when the airplane has rotation about an axis, as in making a turn

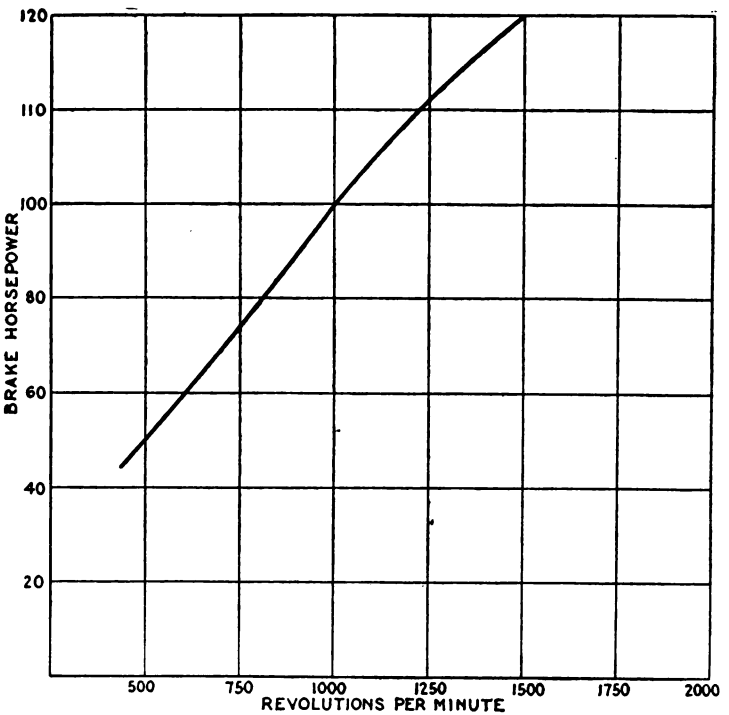

FIG. 11—ASSUMED BRAKE HORSEPOWER OF ENGINE DRIVING VARIABLE-PITCH PROPELLER

or pulling out of a dive. As a matter of fact, an airplane is continually turning to some extent if the flight be in disturbed air.

Each of these forces produces a maximum stress of tension and compression in different parts of the blade, hence the resultant fiber stress at any point will be equal to the algebraic sum of the individual stresses at that point.

It is sufficient to calculate the stress at the points *a*, *b*, *c*, (Fig. 12) along the blade, as these points will be those of maximum stress.

The shear in any case is small and can be neglected in design. The torsion is also small. In good designs, when the thrust is great, the

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point of application of the air reactions is but little removed from the axis passing through the center of gravity of the section.

The curves of stress given are for a three-blade propeller of about 8½ ft. diameter, 5 ft. pitch, absorbing 150 hp. at 1300 r.p.m. The curves are not accurate, as they are intended merely to give a general idea of the order of magnitude of the stresses likely to occur in such a propeller.

The stress caused by centrifugal force is uniform over any section of the blade and varies in intensity at points along the blade, as shown approximately in Figs. 13, 14 and 15.

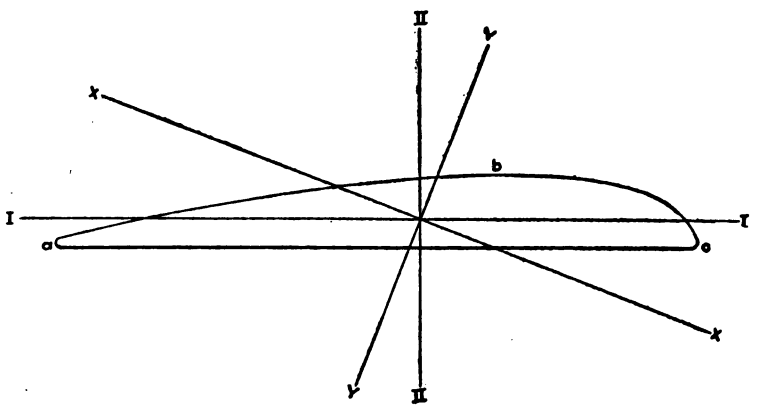

FIG. 12—POINTS OF MAXIMUM PROPELLER STRESS

Steady bending due to aerodynamic forces is caused by torque and thrust. These forces act along $X - X$ and $Y - Y$, respectively for any section, such as shown in Fig. 12. When resolved along $I - I$ and $II - II$ they induce bending moments that cause the fiber stress as shown in Figs. 13, 14 and 15.

Gyroscopic moments are only induced when the airplane is changing its direction of flight. In order to estimate the stress set up in the blades an assumption must be made as to the angular velocity of the propeller axis; that is, as to the precession. There is some question as to the assumption it is reasonable to make in computing the stresses. The type of airplane, size and disposition of the larger masses, such as engines, etc., will affect the rate at which a machine can be turned in flight. In general, the angular velocity in yaw will not greatly exceed 0.35 radians per second. It must be remembered, however, that a steeply-banked turn also involves rotation in pitch.

The maximum angular velocity attained in coming out of a steep dive can be estimated from the characteristics of the airplane and the factor of safety, which determine the maximum high speed attainable and the radius of curvature of the path along which it is possible

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to pull the machine out of its dive safely. A safe value for the angular velocity in pitch for the usual type of present-day airplanes is about one radian per second. Loops have been turned in about 6 sec., which gives about the value mentioned of the angular velocity.

A precession of one radian per second at the normal speed of the engine should therefore be assumed in computing the stresses.

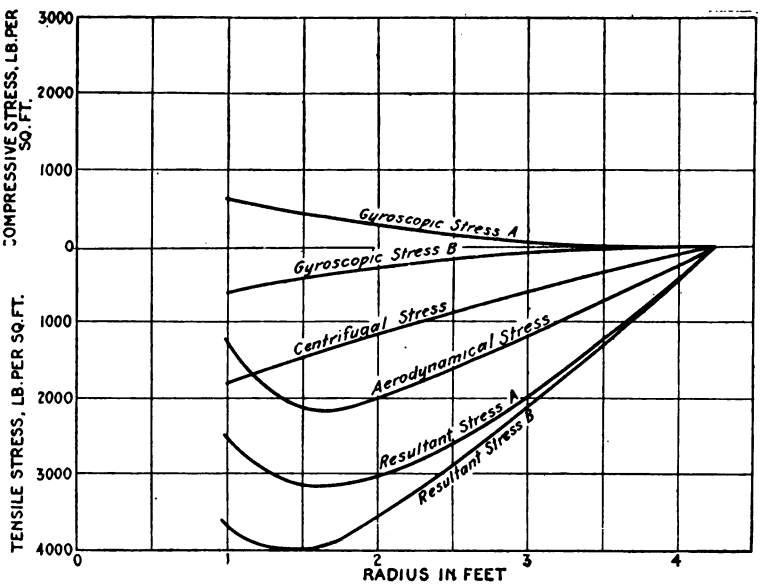

FIG. 13—FIBER STRESS IN PROPELLER BLADE AT POINT *a* (SEE FIG. 12)

The stresses set up by gyroscopic forces are alternating, changing in sign (tension to compression) twice in each revolution of the propeller about its axis.

The fiber stress caused by the gyroscopic moments is given in Figs. 13, 14 and 15. Algebraically adding the fiber stress at the three points chosen gives the approximate value of the resultant fiber stress at those points, as shown in the same figures.

It will be noticed that the maximum stresses occur at some distance out from the hub. To insure a good wearing blade, which will stand up under the necessarily hard usage given it in the field, a factor of safety of not less than five is suggested as being the minimum consistent with requirements when the three principal stresses are taken into consideration.

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SUGGESTIONS FOR IMPROVEMENTS IN DESIGN

These suggestions relating to powerplants are based on the experience of the First Aero Squadron, U. S. Army, in the field.

It is considered extremely poor practice to use shims under the caps of crankpin and crankshaft bearings.

Many American crankcases are not sufficiently rigid in construction. It is believed that crankcase castings are not designed and built, in this country, with sufficient care. Some of the jigs for boring crankshaft and camshaft bearing seats are not so accurate as is desirable.

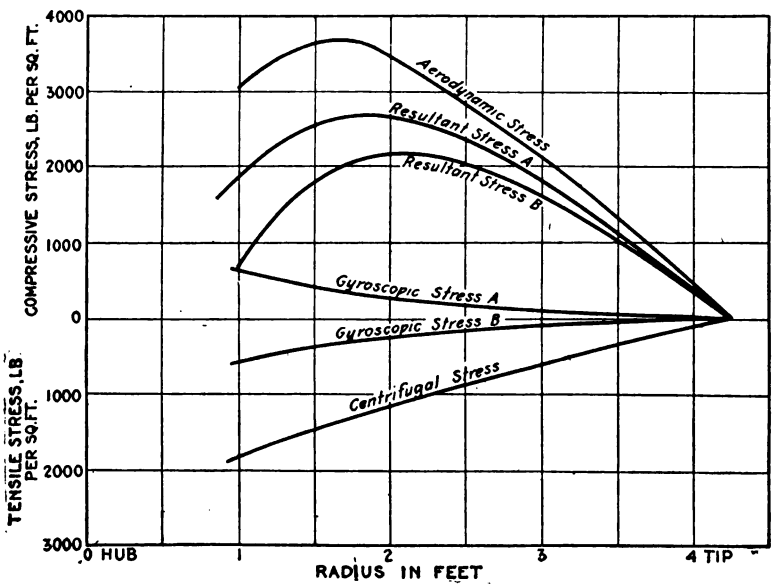

FIG. 14—STRESS IN PROPELLER BLADE AT POINT *b* (SEE FIG. 12)

In some cases it has been found that pistons are not of uniform weight, and are not carefully made.

Lack of interchangeability of parts and *careless workmanship* have been great faults in this country.

Oiling System

This should be by pressure to all important bearings, preferably from a gear pump. Screens should be provided to protect the suction pumps. For engines that have push-rod and rocker-arm valve mechanism, means should be provided to reduce the friction on the exhaust-valve rocker-arm bearing, especially if the valves are more than 1¼ in. diameter.

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Ignition

All military airplanes, except possibly the pursuit type, should have two complete and independent ignition systems.

Engines larger than 140 hp. should have a booster system for starting on battery spark, if a starter is not provided.

It is believed that our magnetos would have much longer life if a more suitable shock-absorbing device between the driving gear and

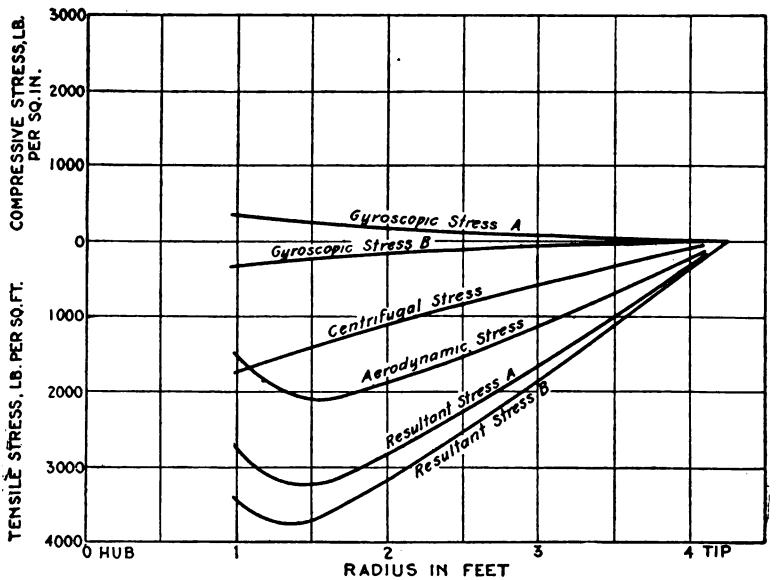

FIG. 15—STRESS IN PROPELLER BLADE AT POINT *c* (SEE FIG. 12)

the magneto shaft were provided. A magneto mounting should be machined so that the magneto shaft will be exactly in line with its driving shaft; dowel pins and dowel-pin holes to preserve this alignment should be provided. No shims should be used here. We have had considerable trouble because of non-uniform and warped carbon brushes.

Fuel Supply

Carbureters should be located in such a way that oil, water and impurities cannot enter them. They should be supported from the engine and not from the frame work of the airplane. They should be supported independently of the intake manifolds, if practicable.

Gaskets for connections in intake manifolds should be as thin as practicable. Manifolds built of copper, brazed, or of steel, welded, are considered preferable to cast manifolds. Steel is considered preferable, but should, of course, be heat treated after welding.

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It is urged that more study and care should be put into the design relating to shape and finish of the interior of intake manifolds and passages. It is believed, in this connection, that much greater efficiency can be obtained by attention to fluid flow.

Cooling System

Radiators should preferably be placed at the leading edge of the upper wing, the header being shaped so as to form part of this leading edge. If it is necessary to place the radiator between the engine and the propeller, the radiator should be circular. The radiator should be provided with a sufficient number of points of support to prevent deformation of the shell owing to shocks on landing.

Care should be taken with the alignment of tubes at the connections in the water-circulating system. A ring reinforcement might be welded to a flanged end of the thin tubing and the face machined so as to make a good fit to the cylinder jacket. It is considered bad practice to expand thin tubing.

DISCUSSION

F. W. CALDWELL:—Perhaps the most troublesome stress encountered with the 160-hp. engines on the Mexican Border is due to the pulsations of the engine. No torque curve is available for this engine, so that the stresses cannot be calculated exactly.

The original drive of the propeller consisted of a hub having two plates keyed together with four splines and having eight ½-in. bolts space on a diameter of 6½ in. As a result the bearing area of these bolts would be $8 \times \frac{1}{2} \times 5 = 20$ sq. in. The torque of the engine is $\frac{160}{\pi} \times \frac{33{,}000}{1400} = 1202$ lb. ft. $=$ 14,400 lb. in. $f_c = \frac{14{,}400}{6.5 \times 20} =$ 111 lb. per sq. in., giving a factor of safety of about 40.

Propellers equipped with this drive began to heat at the hub in a few minutes and after an hour or so were charred at the hub faces and bolt-holes, causing severe vibration, so that they were considered dangerous.

There are 5600 pulsations per minute in this engine and a very small amount of motion between the metal flange and the wood soon heats the wood up to a point where it begins to char. In order to take care of these pulsations it was necessary to increase the diameter of the bolts to ⅝ and then to ¾ in. At the same time a neat fit of the bolts must be secured in the metal flanges and a tight press fit of the bolts in the wooden hub.

The ¾-in. studs and flange nut have 18 threads per inch, and an estimate of the compressive stress on the wood due to setting these up tight gives about 6000 lb. per sq. in. As a matter of fact the flanges can be drawn down into the wood, and it is necessary to keep the bolts set up all the time. I have seen cases where the flanges

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had sunk in 3/16 in. To overcome this a flange 9½ in. diameter is proposed. Excessively large flanges are undesirable, however, owing to the increased weight of the metal and wood. This is merely given as an instance of a stress which might not be foreseen.

The pulsations of the engine are capable of causing vibration unless the moment of inertia of the propeller is great enough to absorb the work of explosion without great speed variation.

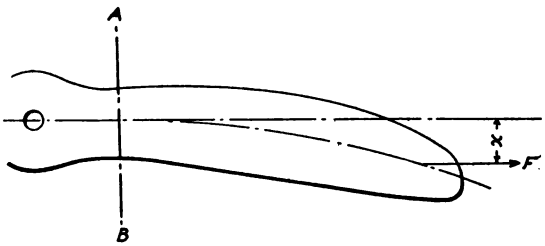

FIG. 16—INCORRECT DESIGN OF PROPELLER

A case of bending and torsion occurs in the type of propeller when the trailing edge is kept straight and the leading edge is curved, as shown in Fig. 16. It is evident from the sketches that the centrifugal force F on the outer portion of the propeller will exert a bending moment, F_x on the section A-B. This is avoided in some designs by spacing the centers of gravity of the blade sections along a straight line through the axis.

It is possible to design a propeller in which all portions of the blade will be subjected to tension only. This depends on the fact that the centrifugal force and the air pressure are both proportional to the square of the revolutions per minute.

If the period of vibration of the propeller blade is synchronous with the period of the engine pulsations, this may cause vibration stresses in the propeller. These stresses cannot be estimated.

When two propellers driven by chain from one engine are used it is ordinarily necessary to use a flywheel on the engine, so that additional weight is added from this source.

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THE ULTIMATE TYPE OF TRACTOR ENGINE

By H. L. Horning

(Member of Society)

Abstract

It is the purpose of the author to analyze some of the factors that have influenced tractor development. He reviews a number of factors on which the usefulness of tractors depends, showing what the farmer is interested in when buying tractors and how the design should be worked out to secure the greatest general efficiency.

The paper then mentions certain general specifications that are required by tractor engines. The author finds that the conditions on about 90 per cent of all farms require a four-cylinder engine of between 16 and 40 hp., operating on the four-stroke cycle. The disadvantages of the two-cylinder horizontal-opposed engine are summarized. An empirical formula is given that can be used to calculate the most satisfactory operating speed of an engine.

In concluding the paper a number of the most important general themes of design are outlined. Particular mention is made of the lubrication system and of the special provisions required for kerosene burning engines.

INTRODUCTION

It would be presumptuous for any man to attempt to prophesy the type of tractor engine, if any, which will ultimately survive, particularly since the tractor industry is the youngest of all hopeful industries. So incomplete is the science of tractor farming, so limited is the development of the art that any man entitled to be called a tractor engineer can be called a pioneer.

Tractors have passed through three distinct phases of development up to this time.

First, steam threshing engines. These hardly could propel themselves owing to the excessive weight per horsepower developed and could haul only the water and coal needed for a journey of a few miles. A large number are being used for threshing service.

Second, steam tractors for threshing and plowing. As compared with the steam threshing engines these were much lighter per horsepower developed and could travel a longer distance on the fuel and water that they could carry.

Third, the tractor equipped with internal-combustion engines, which is developing rapidly along the line of less weight per horsepower and toward the ideal of a drawbar pull equal to the weight of tractor under standard conditions.

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It is the object of this paper to analyze some of the factors that have influenced tractor development, with the hope that a statement of these will aid any thoughtful student of tractor engineering to form his own conclusion regarding the ultimate type of engine.

CONDITIONS INFLUENCING DEVELOPMENT

The old type of tractor was built with the belief that high tractive ability depended entirely on weight, a mistaken idea based on the supposition that road friction was the governing factor in a tractor's ability. This led to design of tractors whose weight was much greater than that of any other moving vehicle. Enormous engines were required to propel these tractors, and many of them labored under the handicap of having only 20 per cent of the horsepower developed available for traction in average soil, owing to the high tractive resistance and inefficient transmission mechanism.

As the development goes on, the usefulness of the tractor becomes broader. The number of farmers who can afford them is increasing, because of the decreased price; they become more reliable and their possible applications are more numerous. The usefulness of tractors increases as:

1—Weight of tractor per horsepower developed decreases.

2—Weight of engine per horsepower decreases.

3—Transmission losses decrease.

4—Tractive ability of drive-wheel becomes greater.

5—The longitudinal center of gravity of tractor and the drawbar hitch are more effectively placed.

6—Output of useful work in unit time divided by the initial cost increases.

7—Total cost per unit of work done decreases.

8—Price of tractor approaches the average income of farms that are suitable for tractor application.

9—Range of conditions under which the tractor can operate successfully broadens.

10—The number of things a tractor can do well on the farm increases.

11—Knowledge of the care and operation of its component parts becomes prevalent among farm users.

12—As the following questions regarding the tractor can be answered to the satisfaction of the farmer:

a—How many plows can it handle?

b—How much does it cost?

c—Will it burn kerosene?

d—What else can it do besides plowing?

e—How long can it last?

f—Is the engine the same type as in his car?

g—Can he get repairs promptly?

An analysis of these twelve factors would cover the entire art of

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tractor engineering. We must, however, proceed with the discussion of those factors relating to the powerplant.

ENGINE SPECIFICATIONS

We will have defined a type of engine if we can establish general specifications that will make for tractor usefulness in the following respects: (*a*) range of horsepower for the tractors that can be used on the average farm; (*b*) most logical cycle for such service; (*c*) number of cylinders; (*d*) mean effective pressure required; (*e*) fuel range; and (*f*) governor control.

Horsepower Required

It is generally conceded that all tractors satisfactory for plowing must have ability to pull not less than two plows on the average soil. At least 90 per cent of all farms can be worked with two to four-plow tractors, taking 10 hp. minimum and 20 hp. maximum at the drawbar. Various power demands on the farm exceed 20 hp. and it is useful to have an engine delivering 30 hp. The tractor engine that will do most of this work does not exceed 35 b. hp. The remaining 10 per cent of the farms will require between 35 and 70 hp. We are chiefly interested in the ultimate engine for the 90 per cent and can therefore figure on engines of between 16 and 40 hp. In establishing these limits we must consider the increased tractor efficiency to be expected in the future and also the low efficiency in some larger types of tractors; we can do this by allowing 8 b. hp. per plow for the most efficient and 10 b. hp. for the least efficient construction.

Available Cycles

The brake horsepower desired from an engine has a profound influence on the cycle, since the area and design of the combustion chamber determine the power produced from any cycle.

Undoubtedly the future holds much in store for the development of engines operating on the Diesel and semi-Diesel cycle, but it is doubtful if their weight can ever be decreased to such an extent that their greater efficiency will overcome the disadvantages of the decreased traction efficiency due to their light weight. In the distant future, when there is a real shortage of the lighter fuels, it may be necessary for mankind to use an engine that will burn the heaviest oils.

The two-stroke cycle engine with its simplicity seems ideal, but up to this time attempts to make a reliable and economical engine have failed. The complications resulting are far worse than those that the cycle attempts to correct.

Other new cycles are being proposed from time to time, but every demand of successful tractor operation seems to be fulfilled by the four-stroke cycle engine. Not the least of its advantages is the intimate knowledge the farmer has of the cycle, resulting from his

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experience with his automobile, stationary engine and the gas tractor as built up to this time.

The horsepower per cubic-inch displacement or the weight per horsepower cannot be improved by any other cycle, all other things taken into consideration. We must therefore consider that the four-cycle engine is and will be the most suitable for tractor service and will be the ultimate type.

Number of Cylinders

The indications are that there is a tendency toward four-cylinder engines. No doubt this tendency is strongly influenced by the prevalence of that type on automobiles. The satisfaction it is giving in sizes between 16 and 40 hp. in automobile and tractor service is the influence that is making four cylinders the standard. Several successful tractors are equipped with two-cylinder horizontal-opposed engines; these have worked very well, considering the difficulties inherent in their design. These can be summarized as follows:

1—The tendency for the shaft to revolve longitudinally in the plane of the crankpins due to centrifugal, inertia and gas forces. This tendency loosens the main bearings by throwing the shaft out of line. The crankpin bearings ride alternately on one side of the pin and then the other, causing damage and necessitating frequent adjustments and replacements.

2—Great weight of reciprocating parts compared with the brake horsepower, augmenting the difficulties enumerated under (1).

3—The high centrifugal forces as compared with the brake horsepower, resulting in effects as listed under (1).

4—Difficulty in cooling the large piston and valve heads necessary in obtained 20 hp. per cylinder.

5—Difficulty of maintaining a perfect mixture in the long intake header as well as the impossibility of attaining high volumetric efficiency with the high velocity necessary for maintenance of mixture quality.

6—Difficulty in lubricating all parts sufficiently without over-lubricating the cylinder.

7—The disadvantageous location of the valves.

8—Infrequency of impulse, the lack of balance and its influence on the transmission mechanism.

PRESSURES AND OPERATING SPEEDS

The history of internal-combustion engines of all types and number of cylinders is a succession of efforts to increase both the working speed and mean effective pressure. Investigation of internal-combustion engines has developed an empirical formula (1) that gives the speed at which the average engine works most satisfactorily.

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The formula takes into consideration the weight of reciprocating parts, efficiency of cooling and lubricating systems and the rate at which inertia forces vary with speed.

$$S = \sqrt{\frac{3{,}000{,}000}{0.04545\ B^3}} \qquad (1)$$

in which S is the most satisfactory working speed; the factor 3,000,000 depends on the cooling and lubricating-system efficiencies

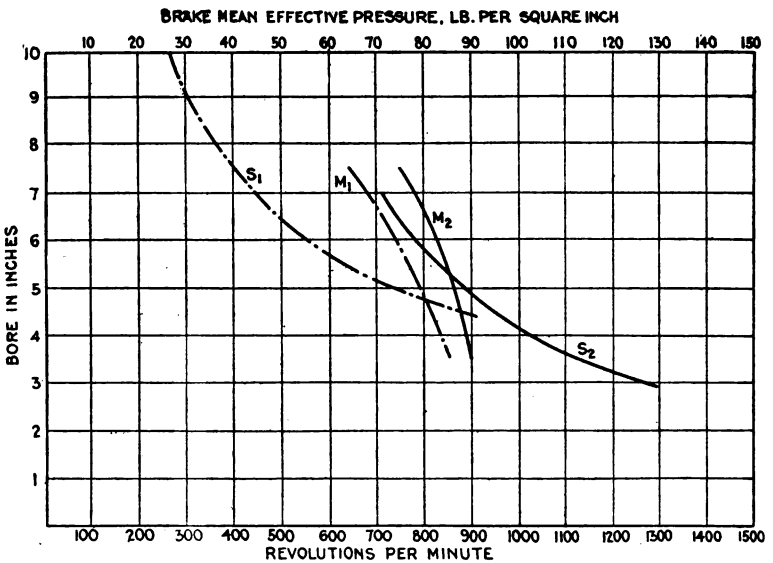

FIG. 1—RELATION OF CYLINDER BORE TO SPEED AND MEAN EFFECTIVE PRESSURE
S_1—Curve of past experience in speed; S_2—Curve of modern experience in speed; M_1—Curve of past experience in mean effective pressure; and M_2—Curve of modern experience in mean effective pressure.

and on the general state of the art; B is the bore of the engine; and the expression 0.04545 B^3 is an approximation for the average piston weights.

In Fig. 1, S_1 shows the relation of working speeds and bore, while M_1 is plotted between bore and allowable maximum brake mean effective pressures taken at the speed of maximum torque.

From past experience it is obvious that small bore engines are much better power producers because they are much favored in both the matter of speed and mean effective pressure. Inasmuch as four-cylinder engines capable of producing a maximum of 40 hp. can be equipped with small cylinders, it seems reasonable to feel that such an engine will be particularly well adapted for tractor service.

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Combustion-Chamber Area

There is an important, though as yet undetermined, relation between the combustion-chamber wall area and its volume; this relation is a governing factor in determining the compression at which an engine can run satisfactorily. Compression and volumetric efficiency determine the mean effective pressure and influence economy favorably. The larger ratio of wall surface to volume in small bore engines makes the problem of cooling easy in the four-cylinder type. Piston heads of diameters up to 5 in. are not difficult to cool. Valves up to 2⅛ in. clear diameter can be cooled satisfactorily, and inasmuch as 20 hp. can be developed per inch of valve diameter at the speed indicated by Curve S_3, Fig. 1, we have another evidence of the advantage of the four-cylinder engine for tractor service.

Performance Records

Inertia forces, which vary roughly as the cube of the bore, have been found to be the principal cause of crankpin-bearing destruction. Our experience with thousands of tractor engines strongly corroborates this statement. In fact we design engines understanding that they will operate, not at the speed set by the governor, but at a slower speed of higher torque caused by the load being always greater than the engine can handle at governed speed.

With the cooling properly taken care of, the length of the period between adjustments is a function of lubrication efficiency and the total number of revolutions. Having built an engine that will cool properly our test is to see how many million revolutions the engine can run between major adjustments. All things considered no other engine of ours has yet equaled the performance of a four-cylinder engine, which in service has run 420,000,000 revolutions with four adjustments of the connecting-rods and three adjustments of main bearings, finishing in good shape with the original valves, pistons, rings, bearings and crankshaft. This no doubt has been duplicated by other four-cylinder engines.

For the purpose of discussing four-cylinder, four-stroke cycle vertical engines from the standpoint of fuels other than high grade gasoline, it is necessary to revert for the moment to the question of combustion-chamber walls. Because of the readiness and lower temperature at which the lower grades of fuel crack into higher and lower hydrocarbons the necessity for better control of maximum cylinder-wall temperatures points toward a range of bore and wall-area ratio to volumes that will give the best results through the automatic thermostatic effect of mere combustion-chamber dimensions.

Four-cylinder engines of either L-head or valve-in-head types fulfill these conditions between the cylinder bore sizes of 3½ to 5 in., which correspond to the range of 16 to 40-hp. sizes demanded for tractor service. Above 5-in. bore engines tend to become "hot," and

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the cylinder wall is favorable for vaporization due to conducted and radiated heat given off at the slower speeds; below 3½-in. bore wall temperatures are too low, but great turbulence due to higher speed of the smaller engine helps to overcome the lower wall-temperature effects. The cylinder walls for burning kerosene should be as hot as possible without danger of a local high temperature sufficient to crack any part of the fuel. This usually occurs near the exhaust valve.

Selection of Bore

The best bore from the standpoint of kerosene burning is difficult to ascertain. Experience shows that 4¼ in. for L-head types seems to give the best results; a larger bore may give the best results for a valve-in-the-head type of cylinder. There is no more interesting problem in internal-combustion engineering than the influence of careful design on the bore, this establishing the most favorable number of cylinders for burning fuels heavier than gasoline.

In working out the combined intake and exhaust manifolds that vaporize the fuels in the mixture during its passage to the cylinder the convenient proximity of the intakes and exhausts makes the L-head and valve-in-head types of cylinders the most frequently used. Tractor engines operate at from 50-per cent to full load practically all the time and with comparatively small variation in speed. The four-cylinder four-stroke cycle engine is therefore easily applicable to burning kerosene, inasmuch as so far as vaporization is concerned the only difficult condition to be met is that which occurs when the engine is throttled.

Because of the narrower explosive-mixture range or air-to-fuel ratios, all of the above favorable factors combine to permit the practical burning of kerosene more easily in the four-cylinder than in any other type.

We have established an ultimate type of tractor engine when we say it shall be a four-cylinder four-stroke cycle vertical engine capable of delivering from 16 to 40 hp. continuously without showing distress at full or overload and of running at speeds varying between 750 and 1230 r.p.m. according to the bore. This engine should run, under favorable conditions, 40,000,000 revolutions between crankpin-bearing adjustments, 80,000,000 revolutions between adjustments of main bearings and 43,000,000 revolutions between grindings of valves.

IMPORTANT ELEMENTS OF DESIGN

Having decided upon a definite type, it may be well to enumerate the general elements of design that need the most attention.

1—A careful layout of the combustion-chamber in order to secure a high uniform temperature of the walls; this means no pockets for steam in the jacket, and a correct direction of cooling-water flow.

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2—Valves arranged to secure favorable heat flow in the exhausts toward the water-jacketed seat and valve guide.

3—Piston head cooled so as to keep temperature of its center below cracking point of fuel.

4—Efficient circulation of water about the spark-plugs.

5—Pistons and rods of light weight.

6—Piston and rings with clearance so as to secure high-temperature performance at medium speed.

7—Stiff crankshaft of material of high elastic limit to withstand abrasion with ample main and crank bearings, particularly center main bearing.

8—Lubrication system designed to convey extraneous heat of pistons, lower cylinder wall, crankcase bearing webs and sides into a sump in which cooling means can be provided to dissipate such heat. The lubrication should be such that if any part fails, auxiliary systems are always at work to prevent sudden failure of bearings and great damage to the engines. The high bearing pressures and temperatures necessitate the use of medium and heavy oils. Breathers that prevent sand and dust from entering the engine should be used. When either the present gasoline or straight kerosene is burned, the increasing content of kerosene results in a rapid drop in viscosity. The oil should therefore be renewed frequently.

9—Crankcase is best in design that is the stiffest and dissipates heat the best.

10—Heavy flywheels to meet sudden peak loads and thus relieve the crankpin bearings of the most severe pounding that they receive.

11—Air cleaners should be used to remove the dust and sand from the entering air.

12—A self-contained governor of both the maximum and constant-speed type is important.

Requirements for Kerosene Burning

13—Provision for burning kerosene. This involves the following considerations:

a—In tractor service when the load remains at over half the full value, kerosene gives reasonable satisfaction, provided properly proportioned combined intake and exhaust manifolds be used and the starting be made on gasoline.

b—Under such conditions the loss in volumetric efficiency due to heating the intake charge results usually in a decrease of from 10 to 20 per cent in the maximum horsepower output, whether gasoline or kerosene is used.

c—When the engine speed increases, the necessity for heat in the intake is less, while when the speed decreases more heat is necessary in the intake. At full speed and power output, slight heating of intake will suffice.

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d—A properly designed combustion chamber, removing the necessity of water injection, is required.

e—The principles of the science and art of burning kerosene, as indicated by my experience, are set forth in several papers by Doctor Charles E. Lucke, and the author testifies to the correctness of his conclusions.

f—A kerosene engine does not carbonize any more than does a gasoline engine; in fact, it stays cleaner than the gasoline engine if the fuel is only comparatively well vaporized.

g—When kerosene is well vaporized so that the mixture reaching the cylinder is in a dry state, a kerosene engine with a correctly designed combustion chamber will not be heated so much as will a gasoline engine.

h—In burning any grade of fuel the carbureter meters and atomizes the fuel; the manifold vaporizes the mixture; the combustion chamber burns it. Of all these the carbureter is the most nearly perfect. The manifolds are next in efficiency. The engines in their present form are the least able to perform their functions in attempting to burn kerosene. The development therefore of kerosene-burning in engines of the prevalent types should start with the engine and end with the carbureter.

AUTHOR'S CONCLUSION

No doubt the greatest criticism of the four-stroke cycle engine is its low thermal efficiency. The future certainly has great things in store for the improvement of this cycle. Perfected systems of spraying the fuel under pressure may offer great opportunities for improvement in the four-stroke cycle as well as in the semi-Diesel type.

The use of heavy fuels is bringing to the front the wonderful possibilities of the newly-developed high-pressure steam boilers. The boiler has been the weak point in steam-driven vehicles but the modern high-pressure type, which delivers superheated steam at a pressure of from 800 to 1000 lb. per sq. in., taken together with the four-cylinder vertical single-acting poppet-valve type of uniflow engine is producing results in thermal efficiency that rival the average performance of the four-stroke cycle internal-combustion engine—particularly when burning cheap oil. After all it is a serious matter to carry the fire box in the cylinder and also to keep the latter clean.

DISCUSSION

H. L. HORNING:—We are all struggling for the existence of the race. An airplane has been the protection of one race of men against the other. The tractor, the most important part of which we are about to consider, has to do with the preservation of the race in this way: it will reduce the cost of living. It is therefore a fundamental thing in the life of the entire world. Nothing since the time that man discovered that a hook on the end of a stick dragged through

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the ground would produce better crops or better living has been so wonderful in its possibilities as the tractor—simply because it must reduce the cost of living. It takes the produce of four acres of ground to keep a horse alive for a year. As the earth becomes populated the struggle of one man to exist at the expense of his fellow man becomes more intense; we must produce more from an acre, we must produce it more cheaply, we must conserve everything that can possibly be consumed by the human race, and we must do it by every possible means. Fundamentally speaking, the tractor is that means.

The tractor engine is a work-horse, not a race-horse. It must work continuously, and in spite of the conditions under which it is operated. There is one difference between the conditions under which a tractor and an airplane engine operate. The airplane engine after about one hundred and twenty hours of service, is overhauled, or many adjustments are made. Fine mechanics are required in the field to look after the engines, which are groomed with the utmost care; this is necessary for the safety of life.

The tractor engine has to work in spite of the conditions of dust and dirt and neglect surrounding it. One of the things that is helping to develop the use of the tractor is the fact that the farmer is becoming better acquainted with engines in general, particularly with the four-cylinder four-stroke cycle type. His ability to take care of his passenger car and his knowledge of the care of the engine will make wide use of the tractor possible.

When a tractor engine goes wrong on the farm it is usually about four to forty miles away from a service station or an expert. When the tractor on the farm stops the entire plant stops because during the day the most important thing for the farmer to do is the job on which the tractor is engaged. The tractor must keep going.

It was proposed some time ago that a self-lubricating packing be used in the water pump. This was so satisfactory that we could do away with the grease-cup. After an investigation we found that grease was actually detrimental to the packing. But instead of using it and thus solving the problem of lubrication of the pump, we discarded the packing for the simple reason that if we put it in without the grease-cup it would wear out some day; the farmer could not get one like it quickly enough and he would take an old rag, a piece of string or binder cord, and pack the gland and go ahead.

We understand that V-belts are good for driving fans. We would like very much to use V-belts, because they are more efficient. But we cannot do it because if the V-belt should go wrong the farmer could not get another one. In the country nobody knows what a V-belt is. We have to use a wide flat belt, so that if anything happens the farmer can take a piece of harness and keep the fan going.

A number of mail-order houses sell oils of various characteristics and the farmer is apt to have such oils. For instance, he will have

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a light oil that runs as freely as water for his Ford car, and he always tries to use it in his tractor engine. The tractor engine cannot run long when a light oil is used. We have to construct engines that will run in spite of the quality of the oil or the infrequency of its renewal. When kerosene is used and the tractor is run slowly, the kerosene condenses and runs down the surface of the cylinder wall and reduces the viscosity of the oil in the crankcase. The result is that in about two or three days after the oil is put in, its viscosity is so low that it has little lubricating value.

Take a piston on a tractor engine that has been running for say eight or nine months; it is frequently the case that if the rings and piston are placed separately on the table any one can tell which ring goes into each groove, for this reason: the viscosity of the oil is so low that by the time it gets to the top of the piston it has lost its lubricating value, and the top ring wears off three times as fast as the bottom ring. In three days we have seen piston grooves wear sideways 1/32 in. Parts of the rings have worn so thin that they broke off and dropped between the piston and the cylinder into the crankcase. This happened in Kansas after two days' service dragging the soil at 106 in the shade.

A large part of this wear is due to the sand that goes in through the carbureter. One of the necessities of efficient tractor work is to keep the sand and dust out of the engine. The difficulties of internal combustion engine operation under tractor conditions are summed up by saying, "After all it is a serious matter to carry the firebox in the cylinder and also keep it clean."

One of the places where the dirt gets is in the crankcase breather. The average tractor while working is encircled in a cloud of dust. Sometimes the engines are placed favorably in respect to dust and sometimes very unfavorably. It is not unusual for half an inch of dirt and dust to be taken from the bottom of a crankcase.

There are a number of ways to protect the engine from dust. A dust remover can be used. There are some of these on the market. The best removes 98 to 99 per cent of the dust in the air by centrifugal action. Another way is by means of a breather, which is a check valve allowing crankcase compression to escape but no air to enter. Another help is to provide a sump in the crankcase so that any dirt or oil or particles from a cylinder that has worn can drop down into this pocket and be separated from the useful oil.

An engine in tractor service usually has its speed determined by the farmer. The engine builder can determine the governed speed of the engine and the governor can be set for that speed. But the farmer drops his plows into the soil and his governor opens the throttle so that finally the engine is producing the highest torque possible at that speed. The average farmer has sunk his plows too deep for the engine to work under such conditions, and the result is that

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the engine slows down to a slower speed and greater torque. Finally a speed is reached at which the maximum torque is just equal to the demands of the plow. That speed may be too slow for the farmer, so he pulls up his plows; then his machine jumps away and he obtains a little higher engine speed with less torque.

This is the typical way the engines are run by farmers. The governor merely takes control of the engine when the load is light, not when it gets heavy. This is real service for an internal combustion engine for it is operating at a speed slightly higher than the speed of maximum torque. At this speed engines heat severely. The problem then is the cooling of the parts.

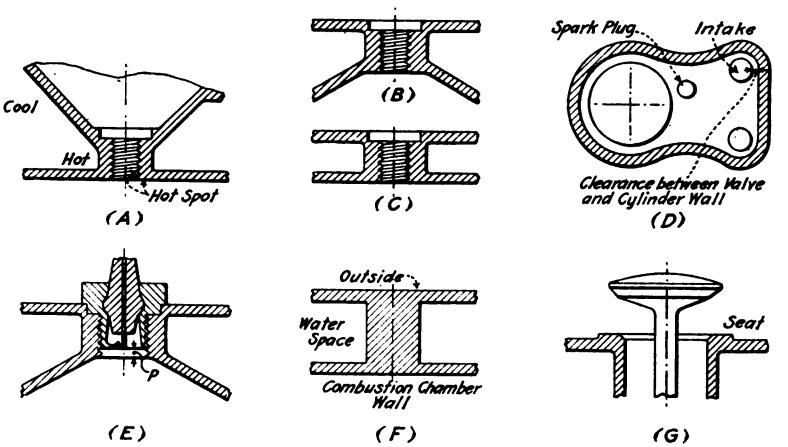

FIG. 2.—CORRECT AND INCORRECT LOCATION OF SPARK-PLUG

One of the most difficult things we encountered when we started to design tractor engines was the combustion chamber. Whenever we attempt to design an engine for tractor purposes we strive for one thing: a proper combustion chamber. The greatest difficulties standing in the way of a proper combustion chamber are the numerous pockets and solid chunks that enter from the outside. The center of the piston head, the center of the valve, and the spark-plugs are all difficult spots to cool.

We found at first it was difficult to maintain a mean effective pressure of 84 lb. per sq. in. continuously, month in and month out. A few years ago more engines were running at 67 lb. m.e.p. than at anywhere near 80 lb. The only way in which we succeeded in getting a higher mean effective pressure was by changing the combustion-chamber design so that the water flowed past the exhaust ports, and that some of the cooling water flowed by the spark-plugs.

A great deal of difficulty would be experienced in keeping cool a

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spark-plug, as in Fig. 2b, for the reason that the water-jacket is so narrow that the natural flow could not occur. Likewise, if there was a depression in the outside, Fig. 2c, which is common in many engines, an attempt to put it in, as in Fig. 2a, would cause a great deal of difficulty, because there is a hot spot, or the place from which the heat must be carried away. The only way of effectively taking care of it is to see that the spark-plug is at the top of the system, so the water will flow up and flow away, Fig. 2e, the combustion chamber at the lower end. Our spark-plug troubles stopped at once when we adopted this system. Likewise we find in the combustion-chamber design, Fig. 2d, that it is necessary to get the wall well away from the valve, so as to give the valves a higher capacity. Too many engines are built with the valve edge and the cylinder wall in close proximity.

We also found that it was of great advantage to put the spark-plug in a position so that the intake gases wash it. That keeps it up into a pocket somewhat away from the exhaust. We have found it advantageous to have the bottom of the spark-plug a little bit back, Fig. 2e, so as not to be swept too much by the exhaust charges.

The piston is difficult to cool, and its diameter is the limiting factor in the size of the engine. The difficulty of getting the heat over to the edge is so great that we have to use fins on the inside of the piston, these being cooled by the splash of the lubricating oil. Oil splashes up in the head, gathers heat, goes down to the crank-case and splashes up again, and that action goes on repeatedly.

We found that four-fifths of the difficulty in cooling the water has been due to the exhaust valve. We do not pay any attention to the rest of the cylinder except to see that one opening is made that will insure the current of cool water coming by the spark-plug. We also make sure that no large chunk of metal, Fig. 2f, projects into the combustion chamber, so that a hot spot can be produced.

It would seem that inasmuch as the heat is given to the exhaust valve, Fig. 2g, by the charge flowing past the seat, that the outside of the valve would be the hottest, and therefore the heat flow might be toward the stem and down the stem to the guides. That is only partly true. A valve operating under very severe conditions attains a cherry-red temperature. The rim, including the seat and a space ½ in. wide of a well cooled valve is cold, but the center part is hot. A certain amount of heat is taken down the stem and we find it desirable to see that the heat is brought down to the valve guide and hence to the waterjacket. The valve guide is brought up as close as possible without compromising the effective gas passage.

Perhaps the most important feature is the width of the exhaust-valve seat. If the seat is too narrow it will not cool; the zone of highly heated valve center will spread out if the valve is too narrow at the seat. If it is wide it will cool back one-half an inch or so; the center

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of the valve will be hot and the rim will be cold. This condition is what is wanted. On the other hand, if with a wide seat the exhaust valve is relatively cool the chance of catching carbon on the seat is greater. On a 2-in. valve we have found that between ⅛ and 3/16-in. gives the proper width. If we could use a 1/16 or 3/32-in. the valve would be better sealed, but it would not last as long, owing to warping and burning.

Kerosene is a mean thing to get into the cylinder, both because it persists in cutting down the oil film, oil sticking to the cylinder walls and spoiling the crankcase, and because the thermal range over which it can be burnt is very small. Experience has shown that when a charge of kerosene strikes a spot in the cylinder at a temperature of above 350 deg. F., that is, beyond the cracking point, it will break up into other constituents. Cracking is exactly what is seen every day in the exhaust as it goes out, a sort of white, steamy appearing smoke of incomplete combustion, accompanied by particularly disagreeable odors.

As soon as cracking occurs in the cylinder the mixture cannot burn properly, because all the proportions have changed. The hydrocarbons produced by the cracking process are different from those in the kerosene intended to be burnt with any particular setting of the carbureter. The average temperature of the combustion chamber must therefore be high and the maximum as near the average as possible. A high average temperature is desirable in that it will vaporize the kerosene globules as they come in; a low maximum is necessary to prevent cracking of the fuel.

Kerosene is not a bad fuel if such conditions are observed. We find that if the kerosene is well carbureted and vaporized we can burn it without depositing carbon in the cylinder. As a matter of fact one way of removing carbon from a cylinder is to put a charge of kerosene in, run the engine for a time and then clean it out. When the kerosene is vaporized imperfectly the constituents of high atomic weights fail to vaporize thoroughly; also perfect combustion is not obtained and the crankcase oil is diluted.

In the manifold lies a solution of the problem of making a correct mixture of the metered fuel and air. The mixture is merely atomized as it enters the manifold, but its proper vaporization depends on proper manifold design and the application of heat. The tendency of engine builders to-day is to get more power from their engines, and naturally this calls for an increase in diameter of the intake manifold. In kerosene engines it is necessary to decrease the area of the intake as much as possible, so as to keep up the velocity of the charge, and then at suitable points, preferably at the bends, heat spots of the manifold so as to vaporize the liquid fuel as it is drawn from the stream of gas. Herein lies an effective solution of the problem of burning kerosene. Because of running at full load kerosene burning is comparatively easy in tractor service.

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The method by which kerosene can be burned in truck engines is by heating the intake charge a maximum amount at low speed and reducing the amount of heat at high speeds and heavy loads. When the engine is run at high speeds and heavy loads the throttle is open and the velocity is such that it whips the mixture so that it is properly vaporized. But at low speeds the mixture is so sluggish that the tendency is to drop the fuel. By having the very hottest manifold heating at low speeds and the least heating at high speed, the average gasoline engine can be run on kerosene.

The development of the engine as it has occurred in the last three or four years has allowed the speeds to increase and also has allowed an increase in the mean effective pressures by having better combustion-chamber design. The result is that we get more power from our engines. This is the direction in which progress is coming in tractor engines. As a matter of fact, the study of this indicates that the small engine has in it the possibilities of developing sufficient power to do almost all farm work. In other words, this great problem of plowing our soil and reaping our crops will be done by a small engine, simply because we must progress along the line of higher speed and higher mean effective pressure. The result therefore will be that the small bore engine of the four-cylinder type will probably do most of the farm work of the future.

Tractor engines must be of light weight, because we must develop a high drawbar pull compared with the weight of the tractor. We must depend not on the tractor or on the character of the traction wheels, but on the placing of the weight of the engine at such a point on the tractor that it will produce the maximum tractive effort.

D. P. DAVIES:—Mr. Horning's paper is exactly in line with the experience that we have had in building tractors and tractor engines. I believe that dust is the greatest factor in shortening the life of tractor engines. I spent two months this past fall in the Southwest and the conditions there are bad in this respect. I have seen tractors that could plow only about forty acres, and on removing the pistons most of the piston rings were gone entirely.

Much educational work must be done to make the farmer realize the necessity of proper lubrication of his engine. I have seen farmers use linseed oil in the crankcase of an engine and expect to get good service. Most manufacturers recommend an oil for the farmer to use. But when he inquires for the brand of oil recommended, the local dealer cannot furnish it and says, "Here, I have something that will answer the purpose; it is every bit as good." But it is not. I believe the tractor engines and the tractors themselves are all right at the present time, but that we must educate the farmer how best to take care of them.

In the last two years we have tried seventy-five to eighty different classes of carbureters for utilizing kerosene. For some of them great claims were made, but in every instance we found that we

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secured just as good results by using any type of good gasoline carbureter that is on the market and vaporizing the kerosene fuel in a vaporizer heated by the exhaust.

More or less kerosene will pass by the pistons and get into the crankcase. Only a short time ago I conducted a test on a 4¼ by 6-in. four-cylinder four-stroke cycle tractor engine, operating at 900 r.p.m. and driving a load of about 22 hp. continuously every day for ten hours; at the end of six days the lubricating oil was taken out of the crankcase and we found that about 9 per cent was kerosene. This is not the worst condition under which that engine could have operated. More kerosene would be found in the crankcase if the engine had been operated under intermittent load. Our experience has been exactly the same as was Mr. Horning's with the different parts that have to be given special attention as to cooling.

HENRI G. CHATAIN:—When the various functions that influence fuel efficiency, such as the lubricating system and the rate at which inertia force varies with the speed are considered, it is difficult to imagine just how Mr. Horning obtained the formula for speed.

I disagree with the curve S_2 resulting from the formula, as being too high for the service that Mr. Horning is speaking about; that is, nearly continuous load on the engine. The curve approximates automobile practice. The 4-in. bore engine is running at something over 1000 r.p.m.; in fact, a little higher than that prevalent in automobile practice.

H. L. HORNING:—The S_1 curve was obtained by taking the total experience that we could gather, plotting such data and getting the average curve of everything that we could possibly find stated; we then found that the S_1 curve was represented by that formula. The formula may be open to criticism from the standpoint of pure mathematics but we have found that as the piston weights increase the time between adjustments of connecting-rod bearings decreases. It is this factor that determines to a great extent the speed at which an engine can be run.

This formula is not derived from a mathematical basis but is a merely empirical formula, so that the curve S_2 is merely plotted from data that have been found satisfactory. The formula of S_2 will vary somewhat from the formula of S_1.

The inertia and the centrifugal forces vary directly as the square of the speed. If at 1000 r.p.m. the inertia forces developed were represented by 100, then at 800 r.p.m. the inertia forces would drop down to 64. If the design of the engine was such that the critical point was around 75, then the life of the engine would be increased by running it at 800 and keeping it under that critical point. The factor 3,000,000 varies with the ability of the designer to cool and lubricate the engine properly.

The average automobile engine with a 4-in. bore would run at

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about 750 r.p.m. The average truck engine would run at a little bit over 800 r.p.m. and the average tractor engine of that bore would run according to curve S_1. But the tractor engine is asked to run at highest speed, because of the insistent demand for great power.

An 84-lb. m.e.p. is difficult to maintain in the average engine. We have run a tractor engine with a 4¼-in. bore twenty-four hours a day at 1600 r.p.m. with full loads; the engine required no adjustment of the bearings, the valves and the spark-plug points came through in excellent condition. That was attained because the combustion chamber design was improved and also because closer attention was paid to the cooling of the exhaust manifold. We were able to run this engine by proper combustion-chamber design with 102 lb. per. sq. in. m.e.p. at a speed of maximum torque without pounding.

The engine performance was the average performance of a car going up the stiffest grade that it possibly could at 45 m.p.h. for a distance the equivalent to 42,000 miles, without an adjustment. This was attained in a laboratory run. The conditions were harder during that test than they would be in the tractor for the reason that the engine was running at 1600 and in the tractor it would probably be running at 900 r.p.m., according to the formula. The lower crankcase had no chance to cool.

At high outputs and high working stresses the average exhaust manifold expands and pulls the cylinders out of line. The result was that we had to place ribs on the exhaust manifold to bring this temperature down to somewhere near that of the room in order to keep the cylinders in line; by doing that and keeping the combustion chamber cool we were able to run at these speeds.

The only way to test a tractor engine is to prevent the currents of air from striking the lower crankcase, which in the tractor engine is a most important part. The lower crankcase so designed as not to dissipate a great amount of heat will not be a success in a tractor engine, any more than will any engine that has no way of dissipating heat from its bearings. If the engine is so designed that it cannot convey heat away from the bearings it would be just as well not to have them.

M. A. SMITH:—Mr. Horning has described the trouble caused by kerosene collected in the crankcase. The refiners of high grade lubricating oils can give assurance that lubricating oil does not "crack" or give off light oil (gasoline or kerosene) when circulating through the engine or when in the crankcase. All kerosene collected in the lubricating oil comes down from the combustion chamber.

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HEAT-BALANCE TESTS OF AUTOMOBILE ENGINES

By Prof. Walter T. Fishleigh and W. E. Lay
(Member of the Society) (Enrolled Student)

Abstract

The authors outline some of the problems that confront the automobile engineer today, showing how the demand for better performance and economy and the ever-increasing cost of volatile fuels has emphasized the necessity for thorough engineering work in the successful automobile manufacturing plant. Believing that the accurate analysis of the heat distribution in a modern automobile engine will be of great value, the authors describe a comprehensive test, made under their direction, of such an engine.

This test includes measurements of the brake horsepower, friction horsepower, fuel consumption and heat losses to jackets, exhaust and cooling air. The engine tested was inclosed in a hood, similar to that used on the car in normal service and an air blast was directed through this hood at speeds approximating those at which the engine would drive a car with a given gear ratio.

The authors analyze the results of the test, emphasizing the small percentage of the total heat supplied that is converted into useful work, especially at the light loads. This fact is made the basis for conclusions that suggest a consideration of means for decreasing heat losses. The possible application of Diesel and other constant-pressure cycles is mentioned, as are also certain modifications in the Otto cycle.

Automobile engineering, in the last five years, has assumed new and far-reaching significance. The development and improvement of the self-propelled vehicle has been so rapid that it is somewhat difficult to trace the relationship of the powerful and luxurious multi-cylinder touring car of to-day to that temperamental single-cylinder "jump-about," its cousin of only a decade ago. The day has passed in which a machine was judged successful if it would run a good deal of the time. The day has passed in which there was a market for automobiles to a public that had not by experience and study been educated up to the merits and possibilities of the different types of automobile units and therefore of the completed whole. The day has passed in which the automobile manufacturer, engineer or salesman need concern himself little with such irritable topics as thermal efficiency, fuel economy, reliability and performance. The problems confronting the automobile engineer to-day are very different from those he had to solve a few years ago; they are more advanced, more comprehensive, more technical. The success of the eight and the twelve, the tremendous improvements in high-speed fours and light sixes, the advent of the so-called magnetic drive, the continued improvement of one steam car and the recent introduction of a second, the developments in air-cooled designs for automobile engines, as well as for airplane work—all these have been possible because of the success-

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ful solution by engineers of problems, which a decade ago were unheard of in connection with automobile development. The engineering department has become increasingly more important and more necessary to the successful automobile manufacturing plant.

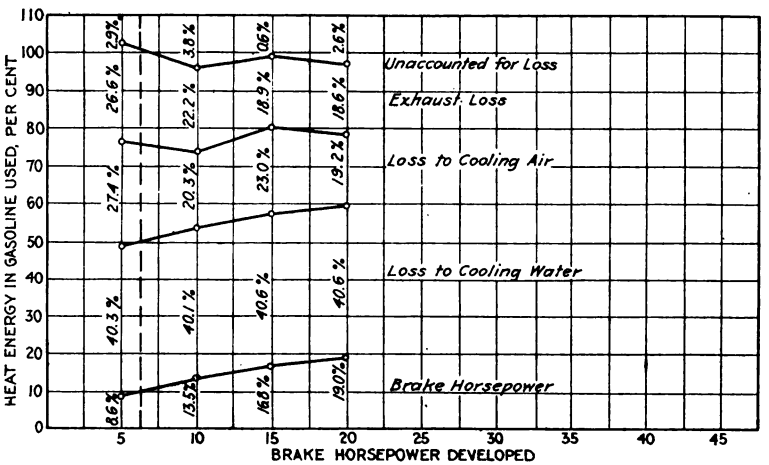

FIG. 1—RESULTS FROM HEAT-BALANCE TESTS OF ENGINE AT 640 R.P.M. (CAR SPEED, 18 M.P.H.)

In the general development, it is only natural that the powerplant should have been given special attention. At present the generally favored type of powerplant for the automobile is the water-cooled multicylinder four-stroke cycle poppet-valve internal-combustion gasoline engine, yet there are other great possibilities. The more we study the characteristics of the present type and the more we inquire into the reasons for its manufacturing "status quo," the more we are convinced that sweeping improvements in design must come or the type be changed altogether. It is an open secret that questions of improved and less wasteful cooling, of changed valve construction with resultant improved combustion-chamber shape as well as increased volumetric efficiency, of decrease or utilization of the energy regularly lost in the exhaust, are being given careful consideration both by automobile and airplane engineers.

The high cost and poor grade of gasoline have had their share in hastening open discussion of the operating characteristics of the present type of engine. Study has been made of the Diesel engine and its adaptability to the automobile; valuable discussion and papers have been had relative to the possibilities of the constant-pressure cycle; improvements in the steam engine with kerosene burner have

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renewed consideration of the advantages and disadvantages of this type of powerplant; improvement in electric cars with increase in operating range has been steady and promising. At no time in the history of the automobile industry have engineers given more careful, more comprehensive and more scientific study to the prevalent Otto cycle and its adaptation to automobile engines. At no time has this

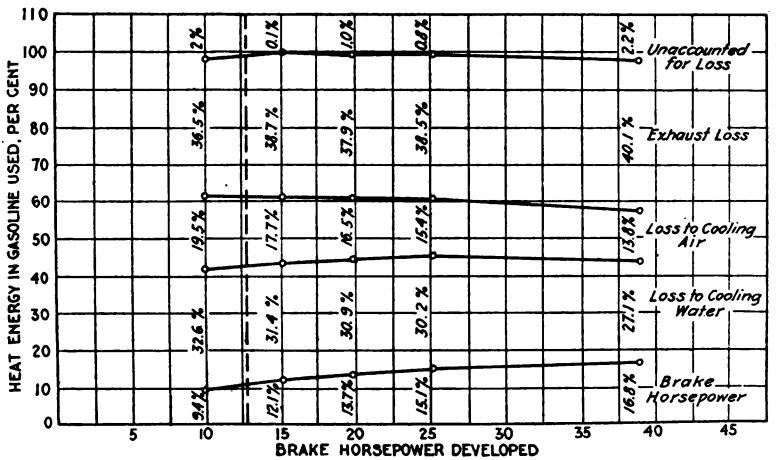

FIG. 2—RESULTS FROM HEAT-BALANCE TESTS OF ENGINE AT 1000 R.P.M. (CAR SPEED, 28 M.P.H.)

study been more unbiased or more critical in the search for improvements, changes or perhaps radical departures from prevailing types.

OBJECT OF HEAT-BALANCE TESTS

Believing that accurate experimental analyses of the energy distribution in typical present-day engines would be of particular value, the heat-balance tests, which are the subject of this paper, were undertaken in the automobile laboratory at the University of Michigan. It is hoped the data presented will be valuable; first, as a definite analysis of a particular typical engine; and second, as a stimulus to thought and consideration of improvements in this type or the invention or adaptation of superior types.

The tests covered by this paper were conducted by advance students in automobile engineering, and in preparation and conduct extended over ten months. Great care was exercised in set-up and procedure and no pains spared in an effort to get reliable and authoritative data. The remarkable accuracy of the heat-balance check is a tribute to the enthusiasm and patience of the operating squads. The engine used was of the six cylinder, L-head type, with 4⅛ by 5¼-in.

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cylinders cast in triplets, recirculating splash lubrication, and forced water cooling. It was thus typical of the medium-speed medium-size six. The curves in Fig. 7 for engine torque, maximum brake horsepower and friction horsepower were obtained in runs made following the heat-balance test. Plans are already under way for continuing this line of research work, first upon an air-cooled six-cylinder engine, then upon a typical high speed water-cooled light six.

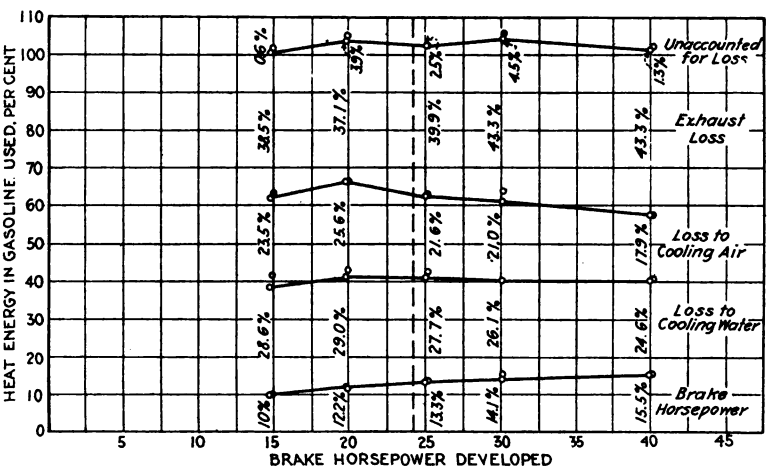

FIG. 3—RESULTS FROM HEAT-BALANCE TESTS OF ENGINE AT 1350 R.P.M. (CAR SPEED, 39 M.P.H.)

As will be clear from the curves (Figs. 1 to 6) runs were made at 640, 1000 and 1350 r.p.m., which represent average operating speeds of the engine, and which for one of the prominent makes of cars in which this particular engine is used, correspond to car road-speeds of about 18, 28 and 39 m.p.h. At each speed, runs were made with the engine developing various horsepowers, which cover the normal operating range. Referring to Fig. 1, for example, at an engine speed of 640 r.p.m. corresponding to a car speed of 18 m.p.h., runs were made developing 5, 10, 15 and 20 hp. (The maximum output at this speed was about 25 hp., as is evident from Fig. 7.) Curves were plotted at each load, using "percentage of heat energy" as ordinates and "brake horsepower developed" as abscissas. Thus in Fig. 1, at 10-hp. output, 13.5 per cent of the heat energy of the gasoline appeared as brake horsepower, 40.1 was lost in the cooling water, 20.3 was lost in the cooling air, 22.2 went into the exhaust, and 3.8 per cent is unaccounted for, that is, can be charged to experimental

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limitations. The ordinate lengths between the various curves give at once the percentage of heat energy that appears in brake horsepower, cooling water, etc. as indicated at the right, and the relative variation in these ordinates graphically indicates the variation in any particular item at the various outputs. When it is considered that the heat energy in the exhaust, cooling air, cooling water and in brake horsepower was actually measured and the sum checked against the total heat supplied by the fuel, the small percentages "unac-

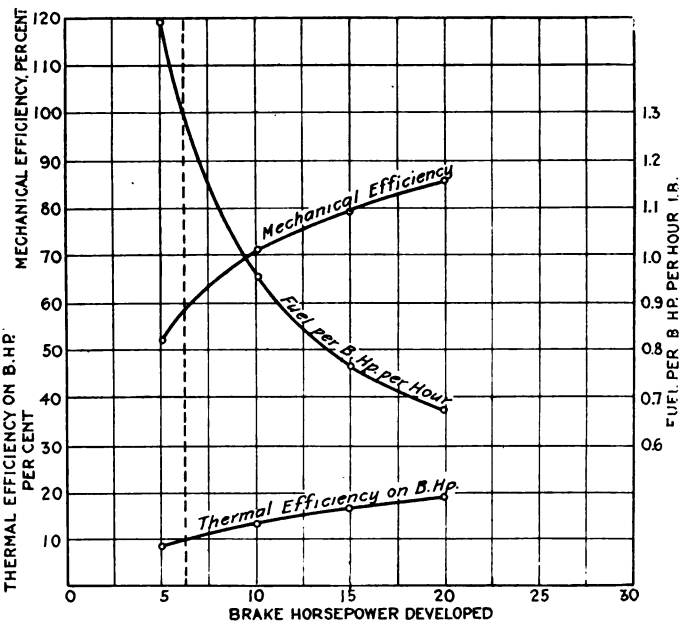

FIG. 4—EFFICIENCIES AND FUEL CONSUMPTION OF ENGINE AT 640 R.P.M. (CAR SPEED, 18 M.P.H.)

counted for" are indeed remarkable. The plus values unaccounted for at 1350 r.p.m. are clearly in error and have given the authors some concern. The entire series of runs at this speed was repeated with special care and precautions, resulting in the secondary points shown.

Estimates for the horsepower required to overcome road and air resistance under favorable conditions for the car in question gave 5 at 18 m.p.h., 9.5 at 28 m.p.h. and 17 at 39 m.p.h. A fair estimate of the efficiency of power transmission through the gear box, differential, rear axle and tires including slippage would give 80 per cent at 18 m.p.h., 75 per cent at 28 m.p.h. and 70 per cent at 39 m.p.h. Upon this basis it is clear that, in order to propel the car under average favorable conditions on the road, the engine would have to develop 6.25 hp. at 18 m.p.h., 12.7 hp. at 28 m.p.h. and 24.3 hp. at

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39 m.p.h. The dash lines at the left, Figs. 1 to 6, are drawn at at these points and indicate therefore the lower limit of the engine power range on direct drive, the upper limit being manifestly the maximum output of the engine.

Figs. 4, 5 and 6 give at once pounds fuel used per brake horsepower per hour, thermal efficiency and mechanical efficiency at the three speeds.

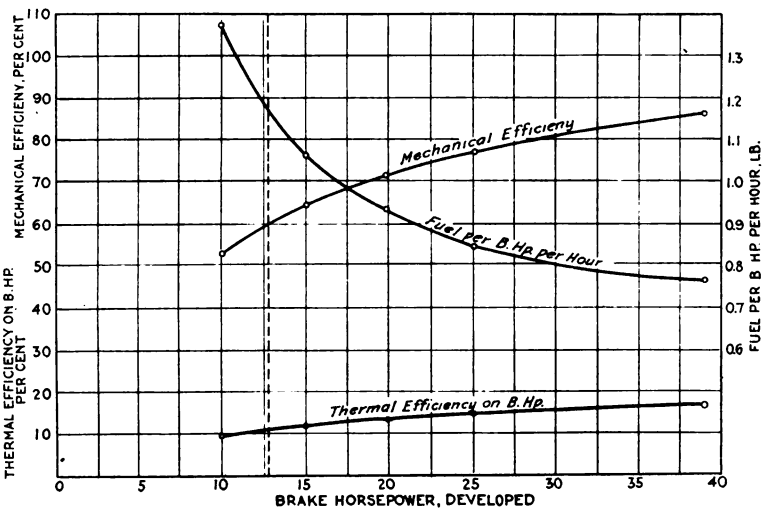

FIG. 5—EFFICIENCIES AND FUEL CONSUMPTION OF ENGINE AT 1000 R.P.M. (CAR SPEED, 28 M.P.H.)

Fig. 7 presents torque, brake horsepower, and friction horsepower curves for this engine obtained in runs taken following the heat-balance tests.

DISCUSSION OF CURVES

Study of the heat-balance curves in Figs. 1, 2 and 3 discloses the following:

1. The heat energy that goes into brake horsepower, or in other words into performing useful external work, ranges from 8.6 to 19.0 per cent. It increases at any one speed as the load is increased. For a given load it increases as the speed is decreased, at 20 hp., for example, the figures reading 19.0 per cent at 640 r.p.m., 13.7 per cent at 1000 r.p.m. and 12.2 per cent at 1350 r.p.m. The highest value (19.0 per cent) is found for the greatest load taken at the lowest speed. At 6.25-hp. output, which estimates of road and air resistance show is required on good level road for propelling the car at 18 m.p.h., the part of the heat appearing as brake horsepower or the thermal efficiency of the engine based upon brake horsepower is 10

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per cent. Interpreting this figure in another way, it means that when an owner buys a dollar's worth of gasoline and uses it in his engine, he develops at the flywheel and delivers to the transmission box just 10 cents' worth of power. Where the other 90 cents goes is indicated by the other relatively long ordinates on the curves.

2. Heat loss to the cooling water was practically constant at 640

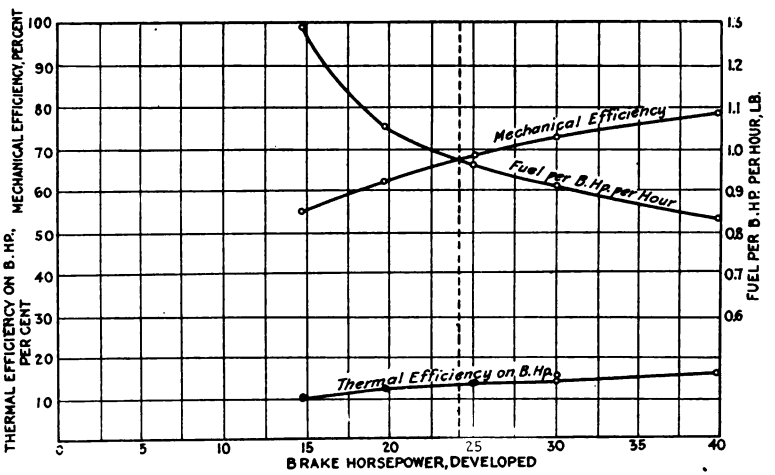

FIG. 6—EFFICIENCIES AND FUEL CONSUMPTION OF ENGINE AT 1350 R.P.M. (CAR SPEED, 39 M.P.H.)

r.p.m. and was about 40 per cent. At the two higher speeds, it decreased with increased output. For a given brake horsepower developed, the loss to cooling water was greater the lower the speed, the figures for 20 hp. being 40.6 per cent at 640 r.p.m.; 30.9 per cent at 1000 r.p.m. and 29.0 per cent at 1350 r.p.m. The average percentage heat loss to cooling water over the complete operating range decreases to a marked degree with increased speed. Interpreting the results of Fig. 1 on the dollar and cents basis again, when an owner buys a dollar's worth of gasoline and uses it in driving his car at 18 m.p.h., he loses 40 cents' worth of the heat energy of the gasoline in or by way of the cooling-water system.

3. The percentage of heat dissipated to the cooling air appears variable at 640 r.p.m.; at 1000 and 1350 r.p.m. there is evident a slight decrease with increased output. In general the loss is greater at 640 and 1350 r.p.m. than at 1000 r.p.m., the figures for 20 hp. being 19.2 per cent at 640, 16.5 per cent at 1000 and 25.6 per cent at 1350 r.p.m. The combined loss to cooling air and cooling water runs as high as 67.7 per cent at 640 r.p.m. at 5-hp. output.

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4. The heat loss in the exhaust at 640 r.p.m. varied regularly from 26.6 at low output to 18.6 per cent at 20 hp. At the two higher speeds it was relatively much larger with slight increase in output. At 1350 r.p.m. a maximum loss of 43.3 per cent was found when the engine was developing from 30 to 40 hp.

In general, it may be observed that the heat loss to the cooling water is relatively large at low speed, being nearly equal to losses from exhaust and cooling air, and relatively low at high speed, when it was somewhat larger than the cooling-air loss alone. Exhaust-gas losses were quite the contrary, being relatively small at 640 r.p.m.,

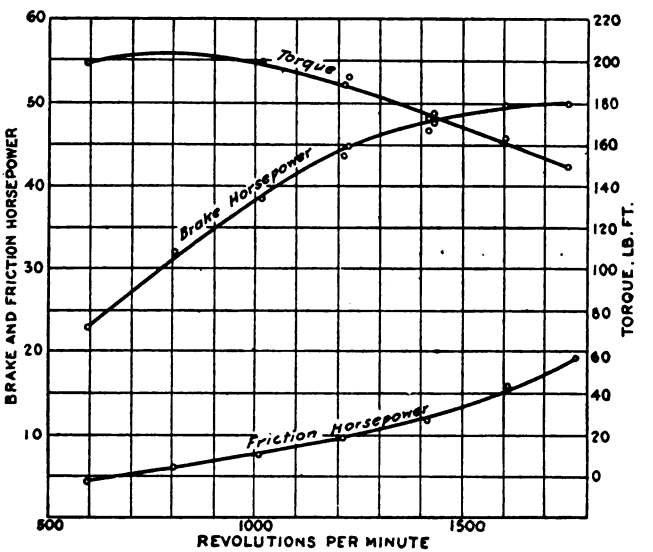

FIG. 7—CHARACTERISTIC CURVES FOR SIX-CYLINDER 4¼ BY 5¼-IN. ENGINE USED TO OBTAIN RESULTS PLOTTED IN FIGS. 1 TO 6

at which they approximate the cooling-air loss, but very large at 1350 r.p.m., where they approximated the sum of cooling-water and cooling-air losses. Cooling-air losses in these tests were larger at 640 and 1350 than at 1000 r.p.m., although the maximum range was only from 13.8 to 27.4 per cent. At any speed, the heat energy effective as brake horsepower is a very small proportion of the total. At any speed, the amount effective as brake horsepower is low under favorable driving conditions, as indicated by the vertical dash lines, improving regularly as horsepower output is increased. At maximum output, a condition seldom met with in automobile operation and a condition under which efficiency is of minimum importance, the best efficiency is found.

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FUEL CONSUMPTION AND EFFICIENCY

Results that appear from consideration of Figs. 4, 5 and 6 are of great significance:

1. The fuel consumption per brake horsepower per hour at any speed was markedly high at low horsepower output, and decreased steadily as maximum output at any speed was approached. Thermal efficiency correspondingly increased at any speed as the output increased. In other words, over the normal operating range, which would extend from the vertical dash-line lower limit to an output from 5 to 10 hp. higher, fuel consumption per brake horsepower per hour is high and thermal efficiency correspondingly low. Under maximum output conditions, the infrequent and unimportant automobile-operating range, fuel consumption is relatively low and thermal efficiency relatively high. For a given brake horsepower developed, the fuel consumed per brake horsepower per hour increases at increased speed, the consumption for 20 hp., for example, being 0.67 lb. per b.hp. per hour at 640 r.p.m., 0.93 lb. at 1000 r.p.m. and 1.05 lb. at 1350 r.p.m.

2. Mechanical efficiency at any speed improves with increased load. For a given load, mechanical efficiency is better at low speeds, the figure for 20 hp. being 85 per cent at 640 r.p.m., 72 at 1000 r.p.m. and 62 at 1350 r.p.m.

TEST RESULTS FOR ONE RUN

The complete data for Run No. 117, in which the engine developed 20 hp. at 1000 r.p.m. (corresponding to car speed of 28 m.p.h.) are given in Tables I to IV. The gasoline used contained 19,800 B.t.u. per lb. Its specific gravity was 0.74 and the Baume reading was 58.8 deg. The gasoline temperature was 69.0 deg. F.

The air conditions were: barometer, 29.06 in. Hg.; humidity, 47 per cent; wet thermometer, 60.0 deg. F.; and dry thermometer, 73.0 deg. F.

The mechanical efficiency (71.7 per cent) will be the brake horsepower divided by the sum of the friction and brake horsepower, or $19.85 \div 27.68 = 0.717$.

The complete heat balance for Run No. 117 as shown by the tables is as follows:

	B.t.u.	Per cent
Input	368,000	100.00
Output (b. hp.)	50,560	13.74
Cooling water	113,750	30.90
Cooling air	60,600	16.47
Exhaust	139,632	37.94
Total	364,542	99.05
Heat unaccounted for		0.95

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The results calculated from Tables I to IV are as follows:

Horsepower Output:
- Brake horsepower 19.85
- British thermal units per hour corresponding to brake horsepower 50,560

Cooling Water:
- Temperature difference (F_o-F_i) deg. F. 18.34
- Heat content, B.t.u. per hour 113,750

Carbureter Air:
- Head, inches of water 0.774
- Flow, cu. ft. per min..... 43.0
- Weight, lb. per hour 188

Exhaust:
- Temperature difference (F_e-F_r) deg. F..... 789.8
- Heat content, B.t.u. per hour.....139,632

Cooling Air:
- Average outlet temperature (F_a) deg. F..... 83.72
- Temperature difference (F_a-F_r) deg. F..... 13.51
- Velocity, ft. per min..... 1,218
- Weight, lb. per hour 18,900
- Heat content, B.t.u. per hour 60,600

Gasoline: (See Tables III and IV)
- Consumption, lb. per hour..... 18.6
- Heat content, B.t.u. per hour.....368,000
- Consumption, lb. per b. hp. per hour..... 0.938
- Parts by weight (see Table IV) for 8.269 parts exhaust gas 0.6325
- Amount burned, lb. 18.6

Water: (see Table IV)
- Parts by weight for 0.6325 parts gasoline 0.9275

TABLE I—ENGINE-TEST RESULTS—RUN NO. 117

Reading No.	Time, H.M.	Horsepower Output			Cooling Water			Carbureter Air, 2× Head, Inches Gasoline	Temperatures, Deg. F	
		R.P.M.		Net Load on Dyn.	Temperatures		Wt., Lb. per Hour			
		Tach.	Counter		Inlet F_i	Outlet F_o			Exhaust (F_e)	Room (F_r)
1	9:24	1017	1002	79.0	118.2	136.5	6200	2.05	860	69.6
2	9:26	1018	997	79.0	118.0	136.3	6200	2.05	860	69.7
3	9:28	1015	1004	79.0	118.0	136.2	6200	2.08	860	70.1
4	9:30	1018	1002	79.3	118.0	136.5	6200	2.08	860	70.1
5	9:32	1018	1001	79.3	118.0	136.5	6200	2.10	860	70.2
6	9:34	1015	1001	79.3	118.0	136.5	6200	2.10	860	70.3
7	9:36	1020	1003	79.0	118.5	136.8	6200	2.10	860	70.5
8	9:38	1022	1003	78.8	119.2	137.4	6200	2.10	860	70.5
9	9:40	1018	1000	79.1	119.5	137.8	6200	2.10	860	70.1
10	9:42	1022	1006	79.1	119.7	138.0	6200	2 10	860	70.1
11	9:44	1022	1000	79.1	120.0	138.3	6200	2.10	860	70.5
Aver. Val.		1018.6	1003	79.1	118.64	136.98	6200	2 09	860	70 21

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TABLE I—ENGINE-TEST RESULTS—RUN NO. 117 (*Cont.*)

Reading No.	Cooling Air									
	Temp. at Outlet F_o				Air Meter Read.	Pos. of Pitot Tube	10 × Velocity Head, Inches Gasoline			
							Hor. Read.		Vert. Read.	
	Therm. 1	Therm. 2	Therm. 3	Therm. 4			1st	2nd	1st	2nd
1	87 2	84.6	82.1	78 9	....	1	0 35	0.35	0.45	0.40
2	87.4	84.8	82.1	78.9	2330	2	0.15	0.15	0.10	0.20
3	87.2	84.8	82.3	79.1	2330	3	1.10	0.80	0.75	1.10
4	87.8	85.2	82.5	79.4	....	4	1.80	1.90	2.50	2.35
5	88.0	85.2	82.7	79.4	....	5	2.50	2.60	2 60	2.60
6	87.8	85.3	82.8	79.5	....	6	2.45	2.45	2.60	2.65
7	88.0	85.6	82.9	79.7	....	7	2.40	2.45	2.35	2.30
8	88.1	85.4	82.8	79.6	....	8	1.90	1 70	2 00	1.85
9	87.8	85.2	82.6	79.4	....	9	0.45	0.60	0 60	0.50
10	88.0	85.3	82.8	79.6	....	10	0.35	0.25	0.30	0.15
11	88.4	85.2	82.8	80.0	....	....	....	....	....	....
Aver. Val.	87.7	85.14	82.63	79.41	2330	....	1.175	1.175	1.255	1.26

TABLE II—FRICTION-HORSEPOWER TEST RESULTS

Reading No.	Time, H.M.S.	Horsepower Output			Cooling Water Temp., Deg. F.	
		R.P.M.		Net Load on Dyn.	Inlet (F_i)	Outlet (F_o)
		Tach.	Counter			
1	9:47:03	1024	1008	30.2	119	139
2	9:48:30	1026	1005	31.5	118	125
3	9:49:30	1027	.....	32.2	122	124.5
4	9:50:30	.....	.....	....	....	....
Aver. Val.	.....	1025.4	1006.5	31.3	119.6	129.5

TABLE III—GASOLINE CONSUMPTION AND EXHAUST ANALYSIS

Gasoline			Exhaust Gas Analysis					
Wt. Consumed, Lb.	Time		Bottle No.	Sample No.	Per Cent by Volume			
	Read., Min.	Elapsed Min.			CO_2	O_2	CO	N
0.5	3.76	1.62	.....	.....	.....	.....	.....	.....
0 5	5.36	1.60	1	1	10.3	0 5	5.5	83 7
0 5	6.94	1.58	2	1	10.0	0 6	5 8	83 6
0 5	8 55	1.61	.....	.....	.....	.....	.....	.....
0 5	10 21	1 66	.....	.....	.....	.....	.....	.....
0 5	11.78	1 57	.....	.....	.....	.....	.....	.....
0 5	13.44	1 66	.....	.....	.....	.....	.....	.....
0.5	15.08	1.64	.....	.....	.....	.....	.....	.....
0.5	16 55	1.47	.....	.....	.....	.....	.....	.....
0 5	18.25	1.70	.....	.....	.....	.....	.....	.....
0.5	19 88	1.63	.....	.....	.....	.....	.....	.....

TABLE IV—DISTRIBUTION OF EXHAUST GAS LOSSES

Gas	Per Cent by Volume	Specific Gravity	Parts Gas by Weight	Parts Carbon by Weight	Gas per Pound of Gasoline Burned, Lb.	Gasoline Burned, Lb.	Specific Heat	Temperature Difference, F_e-F_r	B. T. U. Lost per Hour in Exhaust
CO_2.....	10.15	0.123	1 249	0 341	1 9750	.....	0 218	789.8	6,325
O_2.	0.55	0.089	0.0489	.....	0.0773	.....	0 2175	789.8	247
CO.....	5.65	0.078	0.441	0 1887	0 6970	.....	0.245	789.8	2,510
C in CO...	.....	.....	.....	0.1887	0 2985	.....	.....	789.8	56,400
N_2.....	83 65	0 078	6.525	.....	10.31	.....	0.239	789.8	36,250
H_2O.....	.....	.....	.....	.....	1.4650	.....	.....	.....	37,900
Total...	100.00	.....	8.2639	0.529	14.5243	18.6	.....	.....	139,632

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APPARATUS AND PROCEDURE

The general method of procedure was to determine experimentally: first, the heat energy furnished to the engine in the gasoline; and second, the heat distribution as evidenced in (a) brake horsepower output, (b) cooling water, (c) cooling air and (d) exhaust. Before taking readings on any run, the engine was operated at the given speed and output until conditions of cooling-water, cooling-air and exhaust temperatures were constant. In other words the engine was brought to a condition of running heat balance. Under such conditions, it will be manifest that whatever heat is generated in friction of the parts will appear in the cooling water or be delivered to the cooling air. For this reason friction horsepower does not appear separately in the heat-balance curves, although separate measurement was always made of it for determination of mechanical efficiency. It will appear at once that, within the error of experimental procedure, the energy input should check the sum total of energy output. The set-up, as clearly shown in Fig. 8, included apparatus for determination of weights of gasoline used in a given time, heat value of gasoline in British thermal units per pound, brake loads, speeds, inlet and outlet temperatures of cooling water, quantity of cooling water in a given time, temperatures of cooling air before and after passing the engine, quantity of cooling air passing the engine, temperature of exhaust, analysis and quantity of exhaust.

Measuring Fuel Consumption

The weight of gasoline used in a given time was determined by the standard method as follows: The time required to consume several pounds of gasoline was measured with a stop-watch, time readings being caught (a bell being rung by electric contact made by the scale beam) for pound or half pound increments over a period of at least twenty minutes. The stop-watch was started at the beginning of the period and stopped only at the end. The gasoline, contained in 5-gal. cans, was placed on the scale platform at such height that an average head of 3 ft. was maintained. For each run the specific gravity and temperature of gasoline were determined. The heat value of the gasoline was determined for each batch of 50 gal. with a standard Junker calorimeter, regulated for complete combustion. From four to ten determinations were made on a given sample, the work being continued until results checked reasonably. From the weight of gasoline used per hour and its heat value, the heat energy furnished to the engine was calculated.

The brake horsepower was determined by a Diehl electric-cradle dynamometer of 60-hp. capacity. Approximate speeds and speed changes were read from a magnetic tachometer, driven by belt from the dynamometer shaft. Accurate readings of speed over consecutive one-minute intervals were taken with a revolution counter placed at one end of the dynamometer shaft.

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Cooling-Water Temperatures

Cooling-water temperatures were measured by calibrated straight-stem thermometers, set in conventional oil-filled wells, near the inlet and outlet of the engine. The quantity of cooling water was measured by a calibrated Venturi meter, with conventional manometer. From the quantity of water in pounds per hour and the difference of outlet and inlet temperatures, the heat energy lost in the cooling water was calculated. The standard pump-circulated water-cooling system was used, a special mixing tank (shown in the central background of Fig. 8) being used in place of a radiator. This mixing tank was fitted with an overflow pipe and supply pipes for cold water and steam, the latter two fitted with regulating valves by which the engine inlet-water temperature was maintained at 120 deg. F.

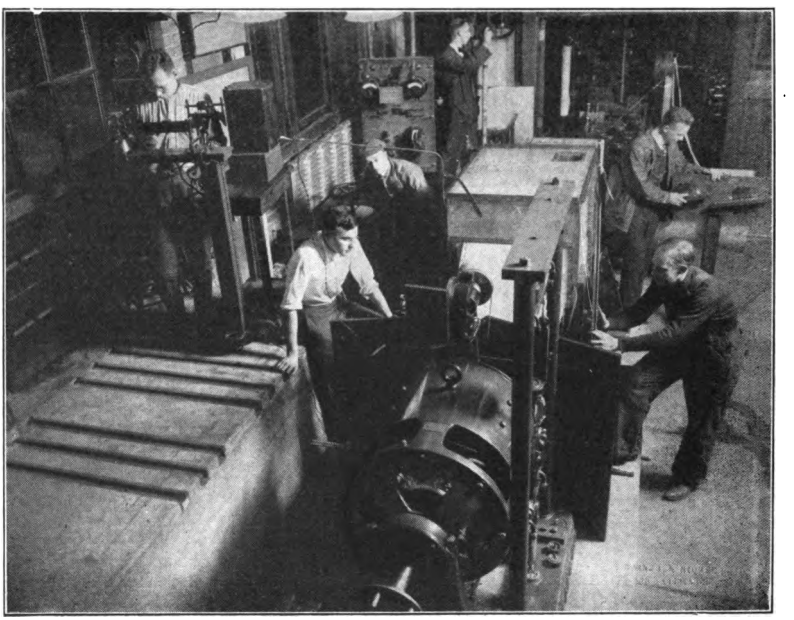

FIG. 8—VIEW OF APPARATUS USED IN ENGINE TESTS

Cooling-Air Supply and Measurement

The cooling air was furnished by a sirocco blower driven by electric motor. The engine was enclosed in an air hood (approximating the engine enclosure on the car) and was connected by an air-tight chute to the blower. In order to approximate actual road-operating conditions, the speed of the air past the engine was regulated. Tests were made with the car operating on the road at 18, 28 and 39 m.p.h. (cor-

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responding to engine speeds of 640, 1000 and 1350 r.p.m.) and the velocity of air passing the engine determined by an anemometer located on the engine. This same anemometer was then removed and placed in the same position on the engine in the laboratory. During each run, the blower speed was so regulated that the anemometer registered the same reading as that obtained on the road at the speed in question. (The glass window through which the anemometer was read is seen on the top of the air hood.)

The volume or quantity of cooling air was measured at the intake of the blower. The air velocity was determined by a series of twenty pitot-tube readings, these tubes traversing the horizontal and vertical diameters of the blower intake-pipe. The temperature of the air entering and leaving the hood was determined by calibrated straight-stem thermometers, one being at the intake pipe of the blower and four in the tail chute of the air hood in such positions as to give an average outlet temperature. Barometer reading, room temperature, and humidity by wet and dry bulb thermometers were determined at least once during each run. Multiplying the volume of air per hour by its weight per cubic foot under the atmospheric conditions obtaining, and by its specific heat, the heat energy lost in the cooling air was found.

Heat in Exhaust Gas

The exhaust-gas temperature was measured by an electric pyrometer, the thermal couple of which was inserted in the exhaust tubing at the point where it emerged from the air hood. Analysis of the exhaust was made with a standard Orsat apparatus. At least two samples of gas were collected during each run over saturated distilled water, analyses being made immediately until the results checked within reasonable limits. From the analysis of the exhaust and the weight of gasoline (assumed to have composition C_6H_{14}) used per hour, the weights per hour of each constituent in the exhaust were found. Multiplying by the respective specific heats and the difference between exhaust and room temperatures and adding the results gave the heat energy carried off in the exhaust. For the water in the exhaust, the total heat was of course used. Where the analysis shows that CO is present in the exhaust, a correction was made by adding the additional heat that would have been liberated if the carbon in the CO had been burned to CO_2.

In order to be certain that the engine was in a condition of running heat-balance before readings were taken, the temperatures of the cooling water, cooling air and exhaust were allowed to become constant. Under such conditions the heat lost in friction (friction horsepower) was absorbed by the lubricating oil, metal parts, crankcase air and exhaust gases, transferred to the cooling water, cooling air and exhaust and there measured. The engine was therefore operated from

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15 minutes to an hour under the conditions of each run before any observations were taken. A preliminary ten-minute run was then made to check the constancy of readings. If this preliminary run was satisfactory, the run proper was begun, continuing 20 minutes or more until satisfactory and complete check was obtained.

REFLECTION AND CONCLUSIONS

The results of these tests emphasize two major points: first, that in the automobile engine as at present constituted, only a small amount of the heat energy available in the gasoline is converted into useful power; second, that within its present operating range, the percentage of heat converted into brake horsepower and therefore the thermal efficiency is lowest for low horsepower outputs, in other words for the usual road operating conditions. The curves, Figs. 1 to 6, present in graphical and condensed form complete operating data for the engine over its normal ranges, and afford a composite picture that well adapts itself to critical and constructional analysis.

The small percentage of heat energy generally converted into brake horsepower suggests: first, a study of the operating cycle; and second, consideration of the possibility of decreasing the amounts of heat given to the cooling water and air and to the exhaust, or the useful application of such heat. Much thought has been given to the improvement or change of the present operating cycle and decided advance is bound to follow the present-day emphasis of efficiency. The difficulties in maintaining reasonable fuel economy under varying volumetric efficiency and its accompanying changes in compression, the adaptation of fixed valve-timing to a variable-speed engine, the inherent shortcomings of the present methods of automatic carburetion and leading of the mixture into the combustion chambers through various manifolds and cored passages and valves in engines expected to operate unfalteringly at 500 and at 2000 r.p.m. and to jump at the touch of the throttle from one to the other, the mechanical problems involved in the valves and ignition in an engine whose combustion chamber approaches the sphere, the necessity for considerable heating of the mixture for present low grades of fuel and the consequent decrease of volumetric efficiency and compression—all these problems have been written upon the research calendar of the automobile engineer.

Ere this, indeed, suggestions and experiments have been made for varying valve timing at different speeds and increasing compression for low-throttle operation. Racing experience has taught much of the value of large valve area and much in the matter of overhead valves and overhead-valve mechanism. Carbureters that mix quantitatively and positively the fuel and air are not impracticable even for the small quantities involved in automobile engines. The application of the Diesel or modified Diesel cycle to automobile engines might solve many of these problems. Recent study of the constant-pressure

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cycle with auxiliary apparatus seems to promise much in the matter of reciprocating-engine development. The ever-elusive gas turbine is yet to be proved impossible or impracticable for automobile use. Even in the face of the present predominance of the gasoline engine, we must admit the possibilities of the improved steam engine with low-grade fuel burner, of the gasoline-electric with improved control, or of the electric with the problems of storage capacity, operating range and battery service-stations solved.

Fields for Future Development

The large amount of heat lost in the cooling water and air affords a vast field for research and future development that will affect not only the automobile, but also the airplane, the tractor and the stationary internal-combustion engine of whatever type or cycle. The probable over-cooling at low speeds and output if ample capacity is provided for extreme demands has already received some attention and the fitting of temperature-controlled by-pass valves, of controllable radiator shutters, of variable compartment radiators, presages much for the future.

Vast improvement can be brought about from an entirely different field of research. Alloy metals can be developed that will stand vastly higher average operating temperatures. The present metal construction can be entirely replaced by a built-up alloy-metal construction that will need no cooling system or at best only an air-draft. Porcelain or other heat-resisting substances can be utilized for part or all of the combustion chamber. Lubricating substances of vastly superior heat resisting properties are surely possible. A fascinating ideal is always a type of engine in which the same wall does not serve as a part of a high-temperature combustion-chamber and at the same time as a lubricated surface upon which the most important high-speed reciprocating mass must travel and have its bearing. Under present limitations, higher thermal efficiency might be had by the use of a cooling liquid whose boiling point is higher than that of the conventional water.

The heat loss in the exhaust, which forms a large percentage at high speeds, is no doubt due to slow burning, induced by low compression and poor carburetion. The changes in cycle that have been suggested would decrease this exhaust loss, but it will probably always be comparatively high at high speeds. Four large poppet valves per cylinder or larger sleeve-valve ports might permit later opening of the exhaust, further expansion and cooling of the burning charge and better efficiency. Pressure injection of both air and fuel has its possibilities. Flexibility and horsepower per unit weight, however, are to-day regarded of such importance as to often outweigh considerations of efficiency and fuel economy, considerations that in the present type might lead toward lower speeds and fewer cylinders.

After the heat lost to the exhaust has been reduced as much as

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possible, the problem can be still further continued in the search for a means of using the heat before it is wasted to the atmosphere. With low-grade fuels such as kerosene, the use of the exhaust heat for preheating the fuel at once suggests itself. Redesigning of the muffler into a heater for cold-weather driving might permit partial use of the exhaust heat during part of the year.

The reduced efficiency and increased fuel consumption under normal light loads at any speed is deserving of the most serious attention. The internal-combustion engine operating upon the present Otto cycle is not well adapted to efficient operation upon partly-opened throttle. The curves presented in this paper testify to that fact. The theory of operation of the cycle leads to that conclusion. The large city is a laboratory in which is being demonstrated daily the low mileage obtained under low-speed and low-throttle conditions. The high cost of fuel and the encouraging demand of the public for more conservative power and more conservative road speeds are spurring us on to the solution of this problem. Larger valves or ports and more of them, variable timing of the valves so as to insure fairly uniform compression, higher compressions with direct fuel injection as in the Diesel or semi-Diesel engine, the constant pressure cycle—all of these are suggestions of rich fields of research. In the direction of this research and advance, the work of the automobile engineer must needs become more important, more technical and more fascinating.

DISCUSSION

H. L. HORNING:—The point Professor Fishleigh makes as to thermal efficiency at high loads is very interesting, inasmuch as tractor engines are running all the time at full or approximately full load. But why with some engines do we get the best efficiency at full load and with others cannot get it at the full load? With the average engine, the maximum thermal efficiency is obtained at from 75 to 90 per cent of the full load capacity. Many engineers would be pleased if some one could throw light on this subject. Is it related to the fact that we must search above the speed of maximum torque for the speed of maximum economy?

FERDINAND JEHLE:—Several months ago, I completed a set of tests that were very similar to those made by Professor Fishleigh, but I used a little different method of getting at the results, principally as regards measuring exhaust heat. I passed the exhaust gas through a calorimeter, measured the increase in temperature of water, which of course made it unnecessary to determine specific heats and the temperature of the exhaust. My results however were not exactly the same; that is, the heat losses were not distributed exactly the same as were those given in the paper. Much more heat was lost to the exhaust and not as much to radiation. I did not measure the radiation separately, but my unaccounted for and radiation losses were not so

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large as is Professor Fishleigh's radiation loss. Does not the radiation loss given include some of the exhaust loss?

The exhaust manifold had to be insulated very well indeed inside of the hood so that some of its heat should not be given out to the cooling air. Of course, the combined loss, the exhaust plus the radiation, will remain the same; but I think we are charging it up against the wrong account if some of that included the radiation from the exhaust pipe. My tests somewhat substantiate Mr. Browne's discussion, inasmuch as I obtained the maximum efficiency at not so low a speed.

W. W. WELLS:—The "research calendar" of the automobile engineer should include the subject of cylinder *scavenging*. If the burned gases left in the clearance space at the end of the exhaust stroke could be replaced by fresh air, the proportion of oxygen in the combustible mixture would be increased and the inert matter that only dilutes the fuel would be decreased. This should have very much the same effect as adding oxygen to the air that enters the carbureter, improving economy somewhat, and adding largely to the maximum output.

It is hard to believe that the subject has been entirely neglected, but I have heard of only one firm conducting any experiments along this line. That was with a six-stroke cycle, and as I remember it, the results were encouraging but not of enough importance to justify the use of a cycle with such an uneven torque.

But is it not feasible to provide some means for scavenging a four-stroke cycle engine? The advantages to be gained would seem to justify some added complication.

The scavenging problem should be studied in connection with the problem of higher compression at light loads, as the same mechanism might perhaps give both of these much needed results.

ARTHUR B. BROWNE:—The authors have indicated, by their outline of future work on other engines, that the present test is only preliminary. This gives promise of obtaining the great mass of data necessary before either the way to greater efficiency will be pointed out, or the inherent limitations of the Otto cycle determined. The work already done shows, however, certain peculiarities that can hardly be called average performance. I have conducted many tests but have never secured maximum thermal efficiency at speeds as low as 640 r.p.m. It is scarcely conceivable that normal efficiencies, on open throttle, drop steadily as the speed increases, unless it be due to some idiosyncrasy of the carbureter used. That this is a fact is indicated by the mixture ratio shown by the air and fuel measurements in the test cited. This mixture is about ten to one. The effect of this over-richness, as evidenced, is a deliberate waste of 56,000 B.t.u. per hour (15 per cent of the total heat) in the exhaust. This loss is not, however, as direct as the foregoing would indicate. The heat was never liberated during combustion, so that a sequence of phenomena follows, more or less conflicting in their effects on the final results. Under these conditions:

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(A) the pressure and temperature could not have been at a maximum.

(B) the expansion curve must have been raised by slow afterburning.

(C) because of (A) loss to the water-jacket must have been reduced.

(D) because of (A) a greater volume of mixture must have been required to produce a given brake-horsepower; that is, the throttle was open wider than was necessary.

We might go on with a multitude of details, but the final net results would be only the well recognized, if little understood, pernicious effect of an over-rich mixture.

Summarized, it is certain that the entire heat balance is disturbed by the use of as rich a mixture as that shown, and it would seem that one of the most fertile fields for investigation is a determination of the heat balance with mixtures of different composition.

I have no doubt that the authors have obtained much data indicating the character of the mixture during each test, and that some if not all of them show instructive comparisons on the point in question. It is possible, indeed, that careful inspection of the character of the exhaust of each test may throw much definite light on the true effect of mixture composition.

It is probable that a considerable part of an 80 per cent heat loss can be saved by the simple adjustment of the carbureter needle-valve; the record that would establish this fact would be of inestimable value.

There is reason to believe that the British engineers have recognized the real waste from an over-rich mixture more generally than has been the case in this country. In fact, during the last visit of the Institution of Automobile Engineers comments on the ill smelling exhaust of American cars were very frequent.

I would like to ask the authors whether they made determinations of methane or hydrogen in exhaust gases, showing the presence of carbon monoxide. Ballantyne has determined a practically constant ratio between free methane, hydrogen and carbon monoxide, and this ratio seems to have been generally accepted in England. If this condition proves true of American gasoline, it would materially affect the computation of the heat loss in the exhaust as set forth by the authors.

PROF. E. H. LOCKWOOD:—The authors' conclusion that at normal operating speeds and loads, the fuel consumption per brake-horsepower is high for the engine under consideration, is true. They have failed to point out however a simple remedy for this condition, whereby the efficiency can be materially improved without waiting for a new cycle, or an improved design of engine.

The remedy is suggested in Figs. 4 and 5, where the mechanical efficiency under normal operating conditions is given as 60 per cent. Here are bad conditions, when with the heat engine limitations only

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15 per cent of the heat energy is converted into work. We allow 40 per cent of the work to escape in the engine, leaving only 60 per cent available to develop brake-horsepower.

The remedy is to use a smaller engine and to persuade the owner that it is for his advantage to carry around less reserve power. In the case before us the engine developed 47 hp. at 39 m.p.h., while it was assumed that 24 hp. would drive the car on the level at this speed. If a new engine of say 28 hp. were substituted, there would still be a reserve for accelerating at the high speed, and the car performance at normal operating speeds would materially improve.

Some designers are carrying out the ideas just advanced and have greatly improved the car performance thereby. I have just made rear-wheel drum tests of a six-cylinder car weighing 2400 lb., and equipped with an engine capable of giving 25 b.hp. at a speed of 40 m.p.h. Tests showed that only 15 b.hp. was required to drive the car at this speed, leaving a fair surplus for grades or acceleration. The thermal efficiency of the engine is no better than that of the one reported in this paper; yet by careful adaptation of the engine to the car and by reduction of internal friction losses, an economy of 30 miles per gallon of fuel was obtained over the range of from 10 to 20 m.p.h.

In the paper the efficiency of power transmission from engine to rear wheels was assumed as 80 per cent at 18 m.p.h. and as 70 per cent at 39 m.p.h. My own observations, based on data from recent tests made in our laboratory, do not agree with these figures. The loss in transmission, due to gears, bearings and tires, has been found nearly constant, making the efficiency of transmission increase with the amount of power transmitted. In the test of the six-cylinder car referred to, the efficiency of transmission at 20 m.p.h. was 68 per cent, while at 40 m.p.h. it was 80 per cent.

C. E. SARGENT:—The paper on heat balance of automobile engines corroborates the results heretofore obtained in efficiency tests of engines of this type over a wide range of loads and proves conclusively the results to be anticipated from a theoretical investigation.

The value of this paper lies in the fact that it brings out the inefficiencies of the under-loaded automobile engine. The conclusions should be an incentive to the engineer to endeavor to develop a more economical cycle or at least devise some method of reducing the losses now so obvious.

With the increased consumption of fuel and its constantly increasing price, the efficiency of the automobile engine must have careful consideration; although when a more efficient cycle was proposed some years ago, the automobile press suggested that thermal efficiency was the last thing to consider in automobile construction. The different losses under different conditions are pointed out in the paper, but it is not shown why the present cycle is responsible for the low efficiencies. The remedies for the losses indicate are suggested timidly, if at all.

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If we were running a car or driving a machine with an electric motor, and applied the brake to make it run more slowly, the result would be obtained but at what a cost. To slow down an automobile engine, we apply a brake, not by friction on a revolving drum, but by converting the engine into a vacuum pump by closing the throttle, thereby causing a back pressure of from six to ten pounds on every square inch of the piston area. With such a handicap the cylinders are not filled but all the gas that gets in is just as rich in hydrocarbons as the quantity used at full load. The amount required to keep the engine going if the brake were removed is but a very small part of the actual amount used in an idling engine.

One reason then why an automobile engine is inefficient at part load is because it must overcome the brake imposed upon it by a restricted throttle. If automobile engineers would study the development of the steam engine, they would find a precedent worth imitating. Instead of admitting a cylinder full of steam, thereby obtaining a maximum mean effective pressure, and releasing it at boiler pressure at the end of the piston stroke, steam engines under normal load close the admission at such a part of the stroke that the expansion of the steam after cutoff does useful work and drops to practically atmospheric pressure before exhaust. If a gas-engine cylinder is but two-thirds filled without a throttle restriction, but with the same compression, a 50 per cent greater expansion and a 25 per cent increase in efficiency will be obtained.

Of course 50 per cent more piston displacement would be required, but with aluminum cylinders to keep down the weight, what is that when compared with the 25 per cent more mileage on the same amount of gasoline. The most inefficient slide valve, now almost extinct, cuts off the steam to get complete expansion and gives fair results at full load, yet throttles the working medium just as we do in automobile engines to reduce the speed or keep it constant when the load becomes lighter. When Corliss varied the cutoff in the steam engine, eliminating the throttling, the efficiency was doubled. We can maintain a much higher thermal efficiency in automobile engines if means can be provided for accomplishing the same results.

A cycle has been heretofore suggested in which gas is admitted during two-thirds of the stroke at full load, thus increasing the compression and diminishing the fuel as the load gets lighter; this cycle promises in practice more than was expected from a theoretical consideration. It reduces the temperature of the exhaust one-half, provides regulation without vacuum brake, furnishes fuel in proportion to delivered load plus engine friction, and will it is believed maintain as high a thermal efficiency as engines of the same size of the Diesel type.

If we can make a successful Diesel engine for automobiles, throttling and its incidental back pressure will be unnecessary; fuel is injected in proportion to the load without reducing the air induced and ignition apparatus will be relegated to the past. While the paper

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brings out in a most satisfactory manner the heat losses of the cycle, it does not seem to emphasize the solution of the problem. It shows that loss to the cylinder walls decreases with the speed, which is what we might expect when we consider that the time of heat difference is reduced, wherein lies one of the virtues of the high-speed engine.

The loss to the cooling water depends among other things upon the difference in temperature of the cylinder walls and the burning charge. Thermosyphon cooling of the water will maintain less difference in temperature and less transmission of heat to the water-jacket. Such a system is much simpler than a pump and thermostat combination. It is quite probable that the tests which the authors propose to make of an air-cooled engine in which the difference in temperature of the cylinder walls and the burning mixture is considerably less than in water-cooled engines, will show a material reduction in the loss to the cylinder walls, this being one cause of efficiency in the air-cooled engine.

The heat loss in the exhaust at high speeds and presumably at full load is attributed by the authors to too slow burning, induced by low compression and poor carburetion.

In my opinion, the compression is greater and the carburetion and combustion more perfect when the load is increased. The increased percentage of heat lost to the exhaust when a cylinder full of gas is compressed is attributable to the lack of expansion at light loads.

When an engine is throttled only a small part of the piston-displacement area is filled with combustible mixture; therefore after compression and inflammation, the mixture expands to the cylinder volume, turning more heat into work, or dissipating it to the cylinder walls.

The data obtained and presented in the paper under discussion are most convincing evidence of the uncommercial thermodynamic operation of the present gasoline automobile engine. Unfortunately engines of this type are more economical at full load, a condition seldom attained in actual operation.

A steam engine, whether used in an automobile or a steel mill, cutting off at its most economical point for average load, rises to the occasion by cutting off later when full load or overload comes on, but with a decrease in efficiency. The reciprocating steam engine, though encompassed by other limitations, is an ideal prime mover for an automobile.

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SOME ESSENTIAL FEATURES OF HIGH SPEED ENGINES

By A. F. Milbrath

(Member of the Society)

Abstract

The author outlines methods for producing high-speed engines with high mean effective pressure and gives data resulting from several years' experimental work. He discusses the desirable stroke-bore ratios; valve area, weight, dimensions, location and timing; compression ratios; ignition requirements; and the location and means for operating camshafts and other valve-actuating mechanism.

Data are given regarding the best material and dimensions for pistons and the desirable number of rings. The physical characteristics of alloy steel desirable for use in connecting-rods are mentioned. Similar data, including dimensions and factors controlling the construction of the crankshaft and its bearings are included. The relation of the inertia stresses set up by reciprocating parts to those due to the explosion and compression pressure on the piston head is indicated, and the maximum total stress deduced. The performance curves of an actual engine, the construction of which is described, are discussed. In conclusion some of the modifications required to adapt a high-speed racing engine to stock production are outlined.

During the past few years automobile engine speeds have increased considerably, especially for certain classes of work. In the early days of the automobile, large-bore slow-speed engines were used, the stationary engines naturally establishing a precedent. These heavy engines were found to be too cumbersome, however, especially when greater powers were required. Not only were the engines heavy in themselves, but on account of their slow speeds they necessitated heavy transmissions, axles and universal joints in order to withstand the heavy torque. To overcome these objections, higher engine speeds and mean effective pressures were developed. The object of this paper is to point out what is possible along these lines, the data given being the result of several years' experimental work.

In designing a new engine one of the first considerations is the piston displacement. In the case of racing engines this is often limited to a certain maximum, usually 300 cu. in.

RATIO OF STROKE TO BORE

The next point to be determined is the stroke-bore ratio. In the high speed engines it is of course necessary to reduce reciprocating weights to a minimum; from this viewpoint a small diameter of

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cylinder with a long stroke is favorable since the weight of a piston increases with some power of the diameter between the second and third, and the inertia forces of the piston vary likewise as long as the piston speed is constant.

On the other hand, however, the weight of the engine will increase with a longer stroke; crankcase diameter increasing with the stroke while the height of the cylinder increases with the length of the connecting-rod, which is about twice that of the stroke. Further, the valve area will decrease with a smaller bore unless large valve pockets are used.

The heat lost to the jacket-water will be the less, the smaller the area exposed to the gases in the cylinder. For a given volume a sphere presents the smallest surface. A shorter stroke therefore has advantages, as the longer the stroke the greater will be the surface exposed and the greater the heat lost to the cooling water.

In Europe stroke-bore ratios as high as two have been used successfully. From the author's experience, ratios of 1.70 or 1.75 have given good results in 300-cu. in. engines.

ENGINE SPEEDS

These will depend principally on the valve area and timing, size and form of inlet manifold, location of spark-plugs, and on the resistance offered by the carbureter to the incoming charge. Valve location will also affect engine speeds to some extent.

The valve area should be as large as possible, but it will be limited of course by the size of the combustion chamber. The largest valve area can undoubtedly be obtained by using two intake and two exhaust valves per cylinder, placed on an angle of about 20 to 30 deg. from the vertical. With this construction, four valves 1¾-in. diameter or 1 9/16 in. clear can be incorporated in a 3¾-in. cylinder without resorting to pockets. This will give ample capacity to develop a maximum horsepower at 3000 r.p.m. On a 300-cu. in. engine this would give an actual gas velocity of about 200 ft. per sec. through the valves when using a valve lift of 5/16 in.

The inlet manifold should be of a size to give a gas velocity of about 175 ft. per sec. The manifold as well as gas passages in the cylinder must be smooth and as free from sharp bends as possible. With some carbureters an extra air inlet in the manifold above the carbureter will increase the power at high speeds, but with most modern carbureters built for this service the air passages are free enough so that the air inlet in the manifold is not necessary.

COMPRESSION RATIO

The volume of compression space for the high speed of engine should be about 18 to 20 per cent of the total volume. This will give compression pressures of about 90 to 110 lb. per sq. in. gage. The combustion chamber should be free from pockets. The more

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nearly spherical the shape the better it is for rapid flame propagation and gas flow, and also for reduction of heat loss to jacket water.

IGNITION REQUIREMENTS

Ignition can be by single-spark magneto; the spark-plug should then be located as near the center of the combustion chamber as possible, as even then great spring pressures are necessary to close opposite sides, as in his opinion this gives more rapid combustion. more power and reduced fuel consumption. The location of valves and the type of valve gear employed will to some extent determine the location and number of spark-plugs per cylinder.

VALVE GEAR AND TIMING

Valves must be made of the best material procurable. Tungsten steel serves admirably. The heads can be extremely thin, increasing from ⅛ in. at the outer edge gradually toward the center with ample fillets at the stem. The valves should be of as light weight as possible, as even then great spring pressures are necessary to close them quickly, and make the valve lifters follow the cams. The diameter has already been discussed, and should be of such size as to give gas velocities of not over 200 ft. per sec. The lift of valves can be as high as one-quarter of the diameter, but for extremely high speeds it is well to keep the lift as small as possible, thus reducing the inertia forces in the valve and the stresses in the springs. Springs must be carefully designed and made of best materials or failure will result.

It is often deemed advisable to use double springs, an outer or main spring, and an inner or auxiliary spring. The stresses in the inner spring are kept lower than in the main spring so that the factor of safety will be large. With the double-spring construction the valve will not fall into the cylinder should a main spring break.

The acceleration of the valve can be ascertained most easily by a graphical method, as usually with the customary shapes of cams, the acceleration is not uniform. When the acceleration is known and the weights of the valve, cam-follower spring-seat and one-half that of spring are known the necessary spring pressure to close the valve in the given time can be calculated by the formula $P = Wa/g$, in which P = spring pressure, W = weight of valve and parts just enumerated, a = acceleration in feet per second per second, and g = acceleration due to gravity.

In actual practice at engine speeds of 3000 r.p.m., spring tensions of 80 lb. with valve seated, have been satisfactory on 1¾-in. valves weighing with accompanying reciprocating parts 0.9 lb. For higher speeds greater spring tensions are necessary, but difficulty is then experienced in securing springs that will stand up for any length of time. In such cases mechanical means for closing valves would prove beneficial. These, however, would add complications.

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Valve Timing

The best valve timing for a high-speed engine depends on so many things that it is possible to get the best results only by actual tests. The timing will be very nearly the following however: The inlet valve opens at or slightly before upper center and closes about 50 deg. after lower center. The exhaust valve opens about 50 deg. before lower center and closes about 10 deg. after upper center. These figures are for engines with large valve areas at speeds of 3000 r.p.m.

Valve Gear

The design of valve operating-mechanism depends on the location of valves and camshafts. Many successful engines have been built with overhead camshafts. Some of these employ a single camshaft while others use two. In the single camshaft type the shaft is located in a housing directly over the center of the cylinders and the valves are operated by rocker levers. In the double camshaft type, the camshafts are located directly over the valves. There is little to choose between these two types. The author has tried both with equal success. The camshaft drive can be through a train of ball-bearing spur-gears from the crankshaft or through bevel gears and vertical shaft. The former works out best with double overhead-camshafts while either can be used for the single camshaft design. The spur-gear construction offers advantages in driving the pump, magneto or other accessory shafts. Gears and shafts should be made of alloy steels so that the weight can be reduced to a minimum.

PISTONS

The most important consideration in pistons for high speeds is light weight. Various materials are used—cast iron, steel and aluminum alloys. Cast iron is the cheapest material and is easily cast to shape, but when the weight is light enough the walls are so thin that the pistons are easily broken. Steel pistons are strong but the machining of them is a tedious operation. Aluminum-alloy pistons have the advantage of ease of manufacture, light weight, high heat-conductivity, and ample strength. Wristpin bearings can be formed directly in the aluminum. Thicker rings should be used however, as thin rings are apt to wear into the aluminum and thus cause a gradual widening of the grooves. Two rings are sufficient for high speed work and even one has been used successfully.

CONNECTING-RODS

Connecting-rods, as well as pistons, should be light, but great strength is also necessary. Either tubular rods or rods of I-beam section can be used. Chrome-nickel or chrome-vanadium steel, heat-treated so that the elastic limit is at least 115,000 lb. per sq. in., should

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be used. It is customary to machine these rods all over to obtain light weight.

Connecting-rods, pistons and all reciprocating parts must be balanced perfectly to insure freedom from vibration.

CRANKSHAFTS

Crankshafts must be made of material as good as that of the connecting-rods, and they must be in perfect running balance. To insure stiffness, a shaft should not be under 2-in. diameter, even for small engines; for 300-cu. in. engines 2¼-in. diameter is better.

With a shaft of liberal dimensions sufficient mass is secured to absorb any vibrations set up by the light pistons and rods. No further balance weights are necessary, especially if the ratio of connecting-rod length to stroke is two or slightly greater.

The area of crankpin bearings requires due consideration in high-speed engines; even with light pistons and rods the bearing pressures due to centrifugal and inertia forces are great.

Aluminum-alloy pistons 3 13/16 in. diameter and weighing 12 oz. have been constructed of ample strength. With wristpin and rings the weight was 21½ oz. The connecting-rods for the same engine weighed 43 oz. Considering one-half of the weight of the rod as a reciprocating mass this would give a total reciprocating weight for piston, pin and rings of 43 oz., or 2.69 lb. The length of stroke was 6½ in. Inertia forces at 3000 r.p.m., due to this reciprocating weight follow:

Crank Angle, Degrees	Inertia Force, Lb.	Crank Angle, Degrees	Inertia Force, Lb.
0	— 2760	100	+ 880
10	— 2695	110	+ 1165
20	— 2500	120	+ 1380
30	— 2195	130	+ 1530
40	— 1800	140	+ 1620
50	— 1340	150	+ 1670
60	— 850	160	+ 1700
70	— 362	170	+ 1707
80	+ 105	180	+ 1710
90	+ 525		

The negative forces act oppositely to piston travel and the positive with piston travel, on the down stroke and vice versa on the up stroke. The centrifugal force due to the weight of the lower end of the rod (21½ oz.) plus the weight of the crankpin bushing (19 oz.) is 2110 lb. at 3000 r.p.m. Taking the explosion pressure as 325 lb. per sq. in., the total pressure on the piston is 3710 lb. The total compression pressure at 90 lb. per sq. in. is 1027 lb. The centrifugal force always acts outward from the center of the shaft and therefore exerts a constant pressure of 2110 lb. on the crankpin bearing.

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At the upper and lower dead-centers the inertia forces also act in a direction away from the center of shaft so that they are added to the centrifugal forces. The final compression pressure on the piston and the initial explosion pressure counteract the above forces.

At the beginning of the suction stroke the connecting-rod bearing pressures are 2760 plus 2110, or 4870 lb.; at the end of the suction stroke and at the beginning of the compression stroke they are 1710 plus 2110, or 3820 lb. This is neglecting the slight error due to back pressure in the suction stroke. At the end of compression stroke the pressure would be 2760 plus 2110 less 1027, or 3843 lb. At the beginning of the power stroke the pressure is 2760 plus 2110 less 3710, or 1160 lb. As the inertia and centrifugal forces overbalance the explosion and compression forces, all of these pressures act radially outward from the center of the crankshaft. For this reason the crankpins always wear most on the inner side. At other positions of the crank than on the dead centers the inertia force and gas pressure would not act radially of course, which would result in a decrease of the total bearing pressure. This shows that the greatest pressures are at the beginning of the suction or at the end of the exhaust strokes.

The crankpin in the engine mentioned was 2¼ in. diameter and 2½ in. long, giving a projected area of 5.625 sq. in. The greatest pressure per square inch is 4870 divided by 5.625, or 865 lb. These bearing surfaces are ample and have stood up very well. With good lubrication it would be safe to allow maximum pressures of 900 to 1000 lb. per sq. in. The oil used must be heavy enough to stand up under these high pressures, high speeds and heat.

The weight of the shafts can be lessened by boring the pins and main bearings. The diameter of this bore can easily be one-half the diameter of the shaft without weakening it appreciably.

Both plain bearings and ball bearings have been used to carry the crankshaft. Plain bearings permit a simpler construction, and also an engine of less weight, but ball bearings reduce the friction and therefore increase the available horsepower. Ball bearings also allow of shorter construction. If ball bearings are used the crankshaft must be designed so that the center bearings can be passed over the shaft from the end and then held in position by bushings or adapters, or it must be built in two pieces. The latter is preferable from the point of compactness. The two halves of the shaft can be fastened together by a large alloy-steel bolt in the center, the bolt being provided with keyways and keys to hold the two ends in proper alinement.

Barrel-type crankcases lend themselves most conveniently to the ball-bearing construction, the crankshaft with all bearings being inserted from the end of the crankcase.

SYSTEMS OF LUBRICATION

Various systems of lubrication can be employed, although a force-

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feed system is to be preferred wherever possible. With plain-bearing crankshafts it is an easy matter to force the oil to the main bearings, then through the crankshaft to the connecting-rods and even through ducts in the connecting-rods to the pistons and piston-pins if desired.

With ball-bearing shafts this is not so easy and it is necessary to depend on splash for lubrication of the engine. Oil rings fed from

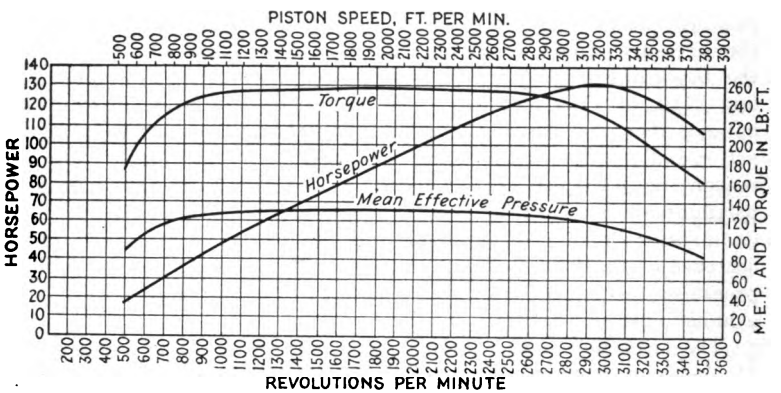

FIG. 1—CHARACTERISTIC CURVES OF WISCONSIN ENGINE

tubes can be fitted to the crankshaft to gather the oil and lead it to the rods under pressure due to centrifugal force. This method has been used successfully on a number of engines in the past.

Separate oil leads are necessary to supply overhead camshafts, with their lifters and rocker levers. Drain pipes to return the excess oil to the crankcase are also required. Part or all of the oil from overhead camshafts can be returned through the housings enclosing the camshaft driving-gears, thus affording lubrication for these gears.

The oil used should be of a heavy quality or of high viscosity when heated, so as to withstand the high pressures. Castor oil is very popular in Europe for this purpose.

PERFORMANCE OF ACTUAL ENGINE

In the above-described engines brake mean effective pressures of about 130 lb. per sq. in. can be obtained at piston speeds up to 2500 or 2600 ft. per min., and of 118 lb. per sq. in. at 3200 ft. per min.

Torque, mean effective pressure and horsepower curves from engines in actual practice are shown in Fig. 1. These were four-cylinder engines built in 1914. Their size was 3 13/16 by 6½ in., giving a piston displacement of 297.6 cu. in. The stroke-bore ratio was 1.7. As the curves show, the maximum horsepower was de-

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veloped at a speed of 2950 r.p.m., or a piston speed of 3200 ft. per min.

The compression ratio on these engines was 5 to 1, which gave a compression of 90 lb. gage, when cranking by hand. The combustion chamber was square in cross-section, of about the same diameter as the cylinder. The valves were set into the head of the combustion chamber on an angle of 20 deg.

Ignition was by double-spark magneto, the spark-plugs being located horizontally on opposite sides of the cylinders.

The valves were 1¾ in. diameter or 1 9/16 in. clear with 5/16 in. lift, giving a full opening for two valves of 2.6 sq. in. With a volumetric efficiency of 100 per cent, this would give a theoretical gas velocity at 2950 r.p.m. of 227 ft. per sec. The actual velocity however was somewhat under 200 ft. per sec.

A single ball-bearing camshaft was carried overhead, operating the valves through rocker-arms. The drive to the camshaft was through a train of spur gears, also carried on ball bearings.

Pistons were made of aluminum alloy and weighed 12 oz. each. With wristpins and rings the weight was 21½ oz. Connecting-rods were tubular of chrome-vanadium steel. Crankshafts were of the same material. They were carried on three ball bearings. The shafts were made in two pieces bolted together in the center. No attempt was made to counterbalance the effect of crankpins or any part of the connecting-rod. The engines ran without vibration through the entire range of speeds.

HIGH-SPEED ENGINES FOR STOCK CARS

High-speed engines are built primarily for racing, where maximum output is the main consideration. For this reason some modifications in stock engines would be necessary to insure durability for continuous service and also to reduce cost of manufacture. Larger bearing surfaces would be necessary in pistons, valve lifters and valve gear; heavier valves and cams with less violent lift would be required; connecting-rods, crankshafts and gears would be drop forged and not machined all over. All of these modifications tend to reduce speed and mean effective pressure so that the output is smaller as compared with that of the racing engine. The results that will be obtained with stock engines depend on the designer's ingenuity in choosing between high output on one hand and durability on the other.

DISCUSSION

RALPH C. CHESTNUTT:—Mr. Milbrath states in the third paragraph of his paper: "In the high-speed engines it is of course necessary to reduce reciprocating weights to a minimum. From this viewpoint a small diameter of cylinder with a long stroke is favorable, since the weight of a piston increases with some power of the diameter between the second and third, and the inertia forces of the piston vary

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likewise as long as the piston speed is constant." In other words, if the weight of the pistons is the same in any two engines, the inertia forces due to the reciprocation of the pistons will be equal, provided the piston speeds in the two cases are the same. This is erroneous. The proof that this idea is incorrect is based on the fundamental law of mechanics that force is equal to mass times acceleration, or $F = Ma$. The equation for inertia force may be written

$$F = \frac{Mv^2}{r}\left(\cos\theta + \frac{r}{l}\cos 2\theta\right) = \frac{wv^2}{gr}\left(\cos\theta + \frac{r}{l}\cos 2\theta\right),$$

in which

l = connecting-rod length, in feet.
w = weight of reciprocating parts.
g = acceleration due to gravity, or 32.2 ft. per sec. per sec.
v = velocity of crankpin in feet per second.
r = crank length, one-half stroke, in feet.
θ = crank angle.

As an example let us consider a 3 by 3-in. engine running at 2400 r.p.m. and a 3 by 6-in. engine running at 1200 r.p.m., each having the same weight of piston.

The term $\left(\cos\theta + \frac{r}{l}\cos 2\theta\right)$ must be the same in both cases and can be dropped from consideration. The constants w and g will also drop out. We then have left $\frac{v_1^2}{r_1}$ and $\frac{v_2^2}{r_2}$ for comparing the inertia forces of the engines with 3 and 6-in. strokes respectively. But v_1 and v_2 are identical; therefore the inertia forces are to each other as $\frac{1}{r_1}$ is to $\frac{1}{r_2}$ or as $\frac{1}{0.25}$ is to $\frac{1}{0.50}$. This shows, then, that the inertia forces due to the reciprocation of the pistons are not the same for the same piston speeds in the two engines, even though the piston weights are the same. It follows then that Mr. Milbrath's statement mentioned at the beginning of this discussion is incorrect.

In dealing with inertia forces it may be of interest to bear in mind this fact: All engines of the same piston displacement having the same reciprocating weight per square inch of cylinder area will have equal inertia forces at the same speed in revolutions per minute, regardless of the stroke-bore ratio.

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DYNAMIC BALANCING OF ROTATING PARTS

By F. Hymans

(Non-Member)

Abstract

The author points out the necessity of obtaining dynamic or running balance of rotating parts, especially in automobile-engine construction. He discusses the manifestations of the lack of static and running balance, such as vibration and high bearing pressures. Formulas are supplied for calculating bending moments and centrifugal forces in a crankshaft that is out of balance.

Methods for obtaining static balance are described and the possible conditions existing after static balance is obtained are treated, with especial reference to the existence of one or more couples.

Descriptions are given of two representative machines that are used to locate couples and correct for them. The principles of operation are made clear and advantages and disadvantages of each type are brought out fully.

The object of balance in the automobile is to eliminate all forces that tend to cause stresses, bearing pressures, or any relative motion of parts not required for propelling the vehicle. To attain this object, balance of the rotating parts, particularly of those that revolve at high speed, is a prime requirement.

The necessity of running balance in high-speed rotors of all kinds was recognized long ago. Many and varied have been the suggestions for the construction of machines that would put such rotors into running balance, some of them showing an excellent appreciation of the underlying principles. There are only three machines however, that have been developed practically. These are: the floating-bearing machine, represented in this country by the Norton machine, the Lavaczeck machine and the Akimoff machine.

Of these the first and last-named will here be investigated, typifying as they do the oldest and the most recent practice. The Lavaczeck machine (Germany) is interesting only as an improvement on the floating-bearing machine. As it is in turn surpassed by the last of the machines named, a discussion of it will be omitted.

Let Fig. 1 represent a body rotating about the axis xx. We can consider this body to consist of a large number of thin slices, which we shall call elements, each disposed between two radial planes. By design or through the unavoidable imperfections in manufacture, the center of gravity of these elements will not lie on the axis of rotation. When the body revolves, each of them will act on the shaft with a radially-directed force, passing through its center of gravity. Fig. 1, for the sake of illustration, shows the several elements with their

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centers of gravity in the same axial plane, but it will be understood that in reality the centers are variously situated.

If the individual centrifugal forces with which the elements act on the shaft are in equilibrium with one another, that is, if for each centrifugal force or group of forces, there is another of the same magnitude but opposite direction, the body will be in running balance. In a body "out of balance" the individual centrifugal forces are not in

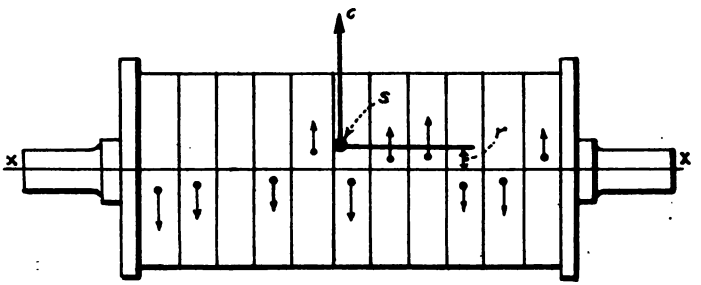

FIG. 1—BODY DIVIDED INTO ELEMENTS

equilibrium. Balance in such a body is brought about by adding material to or removing it from at least three points, thus impressing at such points centrifugal forces to hold in equilibrium the numerous centrifugal forces distributed along the axis of rotation. The latter in magnitude and direction depend upon the eccentricities of the centers of gravity of the various elements upon their mass and upon the speed of rotation.

The cross-sections of such a body will be subject to a bending moment, increasing, as do the centrifugal forces, with the square of the speed. These bending moments due to centrifugal forces serve no useful purpose. On the contrary, they are decidedly undesirable. The capacity of a given size of crankshaft, for instance, to sustain useful bending and twisting moments is lowered according to the amount to which such centrifugal bending moments are present. Plainly the higher the speed of the rotating body, the more important it becomes to limit the centrifugal bending moments as much as possible.

DEFINITION OF IDEAL ROTATING BODY

The ideal rotating body is one of which each element, whatever its shape, has its center of gravity on the axis of rotation. In such a body none of the elements reacts with a centrifugal force when it is rotating. The body is at once in perfect running balance and free from centrifugal bending moments. It must merely be sufficiently

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strong to withstand without undue deformation, the forces due to the useful work it is performing.

Such a degree of perfection is of course impossible to attain, but we can approach the ideal by so designing a rotating body that each cross-section has its center of gravity on the axis of rotation. Owing to imperfections in manufacture there will be slight eccentricities of

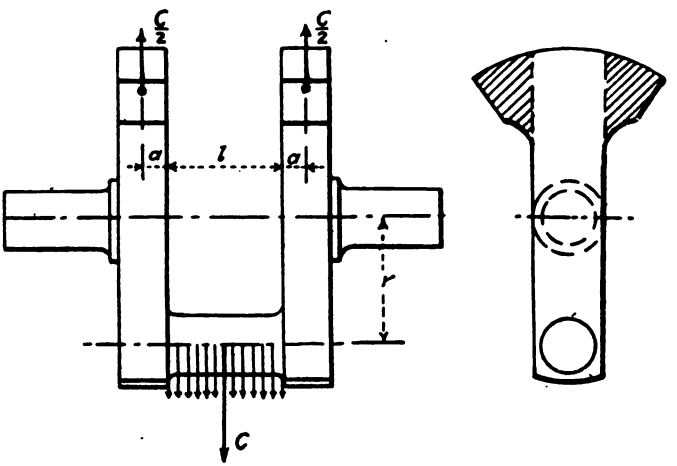

FIG. 2—COUNTERBALANCED SINGLE-THROW CRANKSHAFT

the body's elements; the body will be out of balance as it leaves the shop, but if the aggregate lack of balance has been corrected by the addition or removal of material, the centrifugal bending moments will be small.

A crankshaft cannot be designed as an ideal rotating body. The centers of gravity of the crankpin cross-sections will necessarily be considerably removed from the axis of rotation. Centrifugal bending moments are therefore even theoretically unavoidable, but they can be minimized by compensating weights. Let, for instance, Fig. 2 represent such a counterbalanced double-web single-throw crankshaft. If a portion symmetrical with the crank side is added to the counterweighted side of the web, the hatched portion of both webs counterbalances the crankpin. Upon rotation, the crankpin is subject to centrifugal forces, equally distributed over its length l. The resultant C of these forces is: $C = W\omega^2 r \div g$, wherein W denotes the weight of the crankpin, g the acceleration due to gravity, ω the angular velocity in radians and r the crank length. To compensate for C, the hatched portion of each of the crank webs must be capable of exerting a centrifugal force $(C \div 2)$, whose point of application will be the center

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of gravity of the webs. Centrifugal bending moments occur in the cross-sections of the webs, as well as of the crankpin, but are of im-

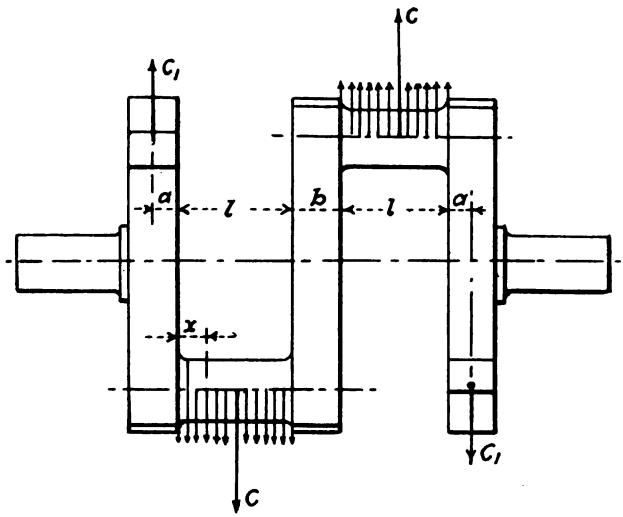

FIG. 3—COUNTERBALANCED TWO-THROW SINGLE-PLANE CRANKSHAFT

portance only in the latter. The maximum bending moment ($M_{b\,max}$) occurs in the center of the crankpin and will be expressed by

$$M_{b\,max} = C \cdot \left(\frac{a}{2} + \frac{l}{8} \right) \tag{1}$$

This bending moment must be added to the bending moments or torsional moments from other causes. It will become smaller, the smaller we can make the distance a, which confirms the rule that a cross-section of which the center of gravity is eccentric in respect to the axis of rotation should be compensated for in a radial plane, as closely as possible to the plane of the cross-section. The hatched portions of Fig. 2, instead of being equally distributed over the width of the webs, should be kept as closely as possible to the inside edges of the latter.

For a two-throw single-plane crankshaft, Fig. 3, the conditions are somewhat different. Each of the crankpins is acted on by centrifugal forces equally distributed over its length and with a resultant C. Both forces C form a couple of which the arm is $l + b$. In order to compensate effectively for forces C, balance weights must be placed on the outer webs. The centrifugal forces C_1, to which they give rise, must form a couple of the same magnitude but opposed to

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that due to the forces C. The distance between the forces C_1 being $2l + 2a + b$, we find without difficulty

$$C_1 = \frac{C\ (l + b)}{2l + 2a + b} \tag{2}$$

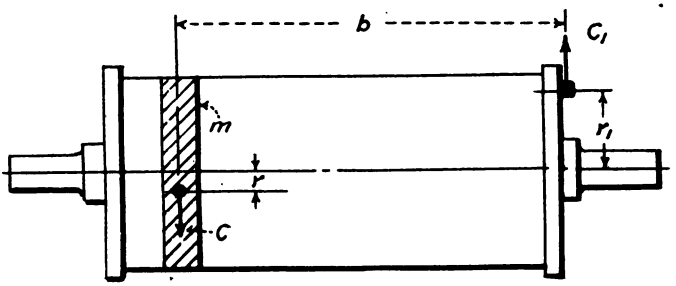

FIG. 4—STATIC BALANCE FOR ONE ELEMENT OF THE BODY

The centrifugal bending moment at a cross-section x of the left-hand crankpin will be expressed by

$$M_b = C_1\ (a + x) - \frac{Cx^2}{2l} \tag{3}$$

or substituting for C_1

$$M_b = C \left\{ \frac{(a + x)\ (l + b)}{2l + 2a + b} - \frac{x^2}{2l} \right\} \tag{4}$$

This becomes a maximum when $dM_b/dx = 0$; hence by differentiating, we find

$$x = \frac{l\ (l + b)}{2l + 2a + b} \tag{5}$$

which determines the cross-section of the crank pin at which the greatest centrifugal bending moment occurs. The maximum centrifugal bending moment is found by substituting for x in (4), whence we obtain

$$M_{b\ max} = C \frac{(l + b)\ (l + 2a)\ (l + 2a + b)}{2\ (2l + 2a + b)^2} \tag{6}$$

Analyzing this formula, it will again be found that the maximum centrifugal bending moment becomes least, when a is made as small as possible. Conventional designs of crankshaft consist of a train of units according to Figs. 2 or 3, each unit being theoretically balanced. That is, if there were no errors in the calculation or imperfections in the manufacture, running balance for such crankshafts would be a real fact, with the centrifugal bending moments reduced to the smallest possible extent.

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The foregoing emphasizes the fact that in a body as it leaves the shop, we can detect, measure and correct only the *aggregate* lack of balance. Unavoidably, the body will be subject to centrifugal bending moments, which can be minimized only by proper design and careful execution.

MANIFESTATIONS OF UNBALANCE

Let us again consider the body, Fig. 1, and apply a well-known law of dynamics, of which the first part says that the center of gravity of a body moves as if all of the body's mass is concentrated therein. Let s be the center of gravity of the body at a distance r from the axis of rotation; s rotates as if all the mass m of the body is con-

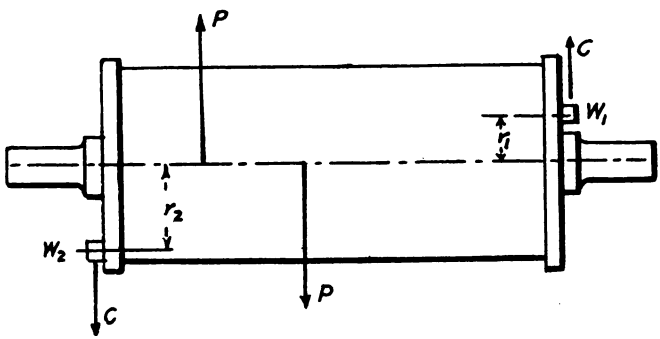

FIG. 5—CORRECTIONS FOR RUNNING BALANCE IN STATICALLY BALANCED BODY

centrated therein, and consequently acts on the shaft with a centrifugal force $C = m\omega^2 v$. One of the manifestations of unbalance in a rotating body is therefore a free centrifugal force, which has its point of application in the center of gravity of the body. Obviously, if the center of gravity lies on the axis of rotation, it has no motion at all and there will be no centrifugal force.

A body so compensated that its center of gravity lies on the axis of rotation is said to be in static or standing balance. Such a body when placed with its axis horizontal and in anti-friction bearings, will remain stationary in any arbitrary position the body is given. The process of static balancing therefore consists in correction for any eccentricity in the center of gravity of the body.

Quite generally, static balance is obtained by rolling the body on horizontal ways. The unbalanced body will come to rest with its center of gravity vertically below the axis of rotation, and static balance is brought about by adding a single weight to the "light side" or by removing material from the "heavy side" of the body. Suppose

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we apply this process with the unbalanced body, Fig. 1, and obtain static balance by attaching to its right-hand flange a single weight of the required mass. The eccentricity of the center of gravity of the body for which we have compensated in this manner, is of course the aggregate of the eccentricities of the centers of gravity of its individual elements; that is to say, what we have accomplished in a single step is equivalent to compensating at the right-hand flange of the body for the eccentricity of the center of gravity of each of the elements of the body separately. Let us, in theory, apply this process and see the result.

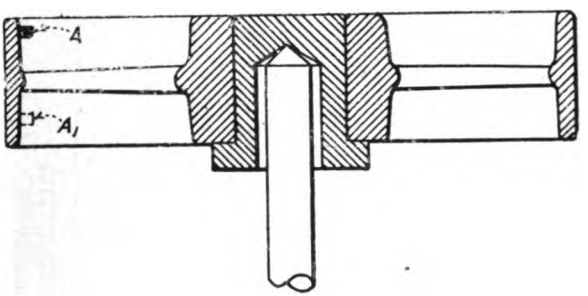

FIG. 6—SHOWING OPERATING PRINCIPLE OF CONE-BALANCING MACHINE

Considering for instance the element, Fig. 4, indicated by the hatched portion, having a mass m and its center of gravity at a distance r from the axis of rotation. In order to compensate for the eccentricity of the center of gravity of this element, we require a weight at the right-hand flange of the body at a radius r_1, of which the mass m_1 must satisfy the relation—$m_1 r_1 = m r$.

When the body rotates, however, there will be a centrifugal force ($C = m\omega^2 r$) due to the element, and a centrifugal force ($C_1 = m_1\omega^2 r_1$) due to weight m_1. These forces, although acting in opposite directions, will be equal in magnitude and form a couple. We have consequently compensated for the eccentricity of the center of gravity of the element, but in doing so introduce a centrifugal couple acting in an axial plane. Proceeding in this manner to compensate for the eccentricities of the centers of gravity of the other elements of the body, we will introduce as many centrifugal couples as there are elements. The resultant of a number of couples is again a single couple. Thus, while static balance has been obtained, the body is still subject to a centrifugal couple acting in an axial plane. This couple has a fixed position relative to the body and rotates with it.

Let Fig. 5 represent the body as statically balanced and subject therefore to the centrifugal couple consisting of two equal but oppositely directed forces P, each acting perpendicular to the axis of

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rotation. What will be necessary to bring about running balance? A couple can only be compensated for by another couple acting in the same plane, of the same magnitude, but of opposite effect. To impress such a corrective couple on the body we evidently must attach in the plane of the couple P two weights w_1 and w_2 placed at such a distance from the axis of rotation that they give rise to two equal but oppositely directed forces C. Usually these weights are made equal and spaced at equal distances from the axis of rotation. Instead of adding weights, it is common practice to remove material at opposite sides. The body is now in perfect running balance; it will be seen

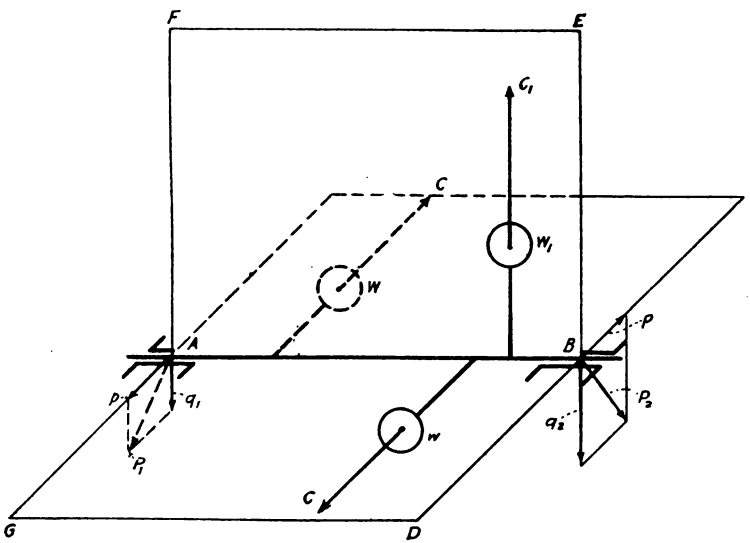

FIG. 7—FORCE AND CENTRIFUGAL COUPLE ACTING ON ENTIRELY UNBALANCED BODY

that the only bearing pressures are those due to its weight or to the useful work it is performing, provided of course there are no undue deformations that destroy its balance.

CONDITIONS OF COMPLETE BALANCE

Summing up, the result of the foregoing is as follows:

First: Complete running balance in a rotating body can be brought about only by two distinct operations, thus securing static and dynamic balance.

Second: Static balance corrects for eccentricity of the center of gravity of the body. It can be obtained by adding or removing material at any point in the axial plane containing the center of gravity.

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Third: After obtaining static balance, the body is still subject to a centrifugal couple.

Fourth: Dynamic balancing serves to eliminate such a couple. This can be accomplished only by adding or removing material at *two points* in the plane of the centrifugal couple, one above and the other below the axis of rotation, but each situated in a different radial plane.

In the second and fourth conclusions are enumerated the least number of corrections to secure running balance in an unbalanced body. Any scheme that proposes to employ less will not produce running balance. For instance, in the so-called cone-balancing machines

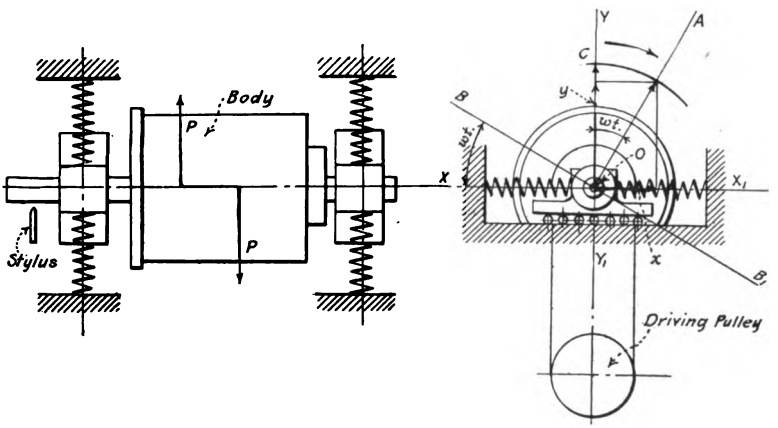

FIG. 8—REPRESENTATION OF FLOATING-BEARING BALANCING MACHINE

for pulleys and the like, Fig. 6, the hub of the body to be balanced is fitted with a hollow plug, which adapts it to be carried on top of a vertical spindle, cone-shaped at the end. While the body is at rest, it is statically balanced by attaching to it a weight A consisting of clay or similar material. The body is then rotated at high speed, and the weight A is shifted up or down in a vertical line, until it is found that at A_1 for instance, the body runs fairly true. The lump of clay is now replaced by a permanent weight and the body is assumed to be in running balance. The endeavor here is to obtain running balance by means of a correction at one point only, but since three is the required minimum, the method should be rejected. Irrespective of whether the weight is at A or any point vertically below A, there is static balance only, and a centrifugal couple that is not compensated for remains. The magnitude of this centrifugal couple depends, however, to some extent on the position of the weight, and by

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shifting this in a vertical line with respect to the body, we can determine that position at which the centrifugal couple is a minimum. What this machine effects is static balance only, minimizing, however, the remaining centrifugal couple; but it never can be used to obtain running balance.

Of course, the smaller the axial dimension of the body, the smaller the centrifugal couple tends to become. This will be realized when we refer again to the hypothetical method of obtaining static balance in a body by compensating for each of its elements individually. In Fig. 4 the arm of the couple introduced by statically compensating for the hatched element is *b*. The smaller the axial dimension of the body, the smaller the arm of each elementary couple becomes, and, all things being otherwise alike, the smaller becomes the magni-

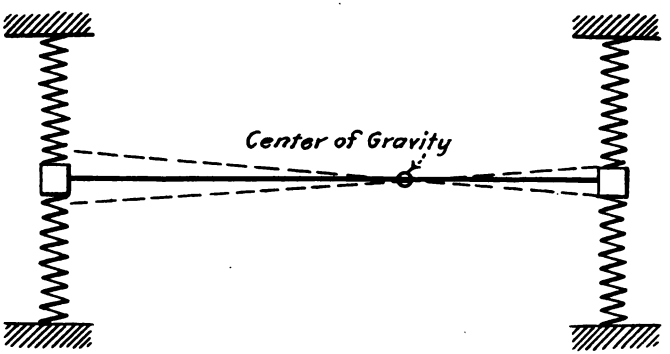

FIG. 9—SHOWING HOW BODY IN FLOATING-BEARING MACHINE OSCILLATES AROUND CENTER OF GRAVITY

tude of the resultant centrifugal couple. For bodies of small axial dimension, such as pulleys and gears, of moderate speed and supported on a fairly rigid foundation, the approximate balance, as obtainable with the cone machines, may in many instances be sufficient. If the body—for all practical purposes—can be considered to be a true disk, even ordinary static balance may suffice.

Since perfect running balance in a body can be obtained only by compensating for a free force and a couple, any body that reacts upon rotation with a force and a couple, will be a true model of an entirely unbalanced body. Such for instance is the body, Fig. 7, consisting of two equal weights w and a third weight w_1, the two weights w being attached at different points of the axis of rotation, at opposite sides thereof, and at equal radii. Upon rotation the two weights w react on the shaft with a centrifugal couple consisting of two equal forces C, while the weight w_1 reacts with a free force C_1. It will be noted, as is universally the case, that the plane of application of the couple

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is different from that of the force, the former acting in the axial plane *ABDG* and the latter in the plane *ABEF*. On account of the above forces (not considering the weight of the body) the bearings *A* and *B* act on the shaft with a couple consisting of the forces p in order to balance the centrifugal couple, and with forces q_1 and q_2 on account of the free force C_1. The resultant of these forces is a bearing pressure P_1, at *A* and P_2 at *B*, both rotating with the body and resulting in needless wear and a useless expenditure of power to overcome the friction. This does not, however, include all the detrimental effects of the lack of balance.

Let it be assumed that the bearings *A* and *B* are the crankshaft bearings of an automobile engine. The rotating forces P_1 and P_2 are transmitted through the crankcase fastenings to the frame of the car, and the latter, being yieldingly supported on springs, is set in motion.

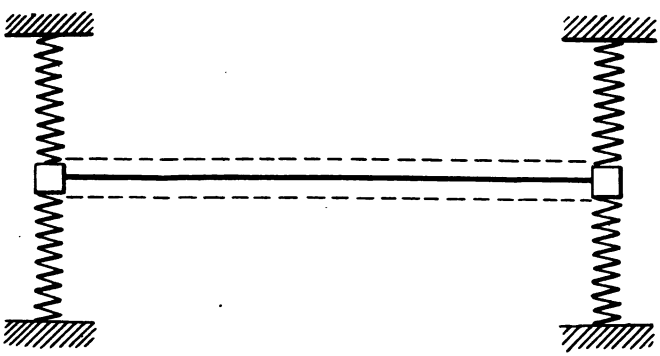

FIG. 10—BODY IN FLOATING-BEARING TYPE OF MACHINE VIBRATING PARALLEL TO ITSELF

The forces imparted to the frame continually change in direction with the forces P_1 and P_2, so that the only effects possible under the conditions are vibrations. Together with these vibrations there occurs a loss of power; for the energy that maintains the vibrations must be delivered by the engine. Clearly, running balance, at least of the main rotating parts in the automobile, is a necessity, requiring, as stated before, accurate static as well as dynamic balance.

Machines can be so designed that both balancing operations can be performed on one and the same machine, although in successive steps. However, the complications in the design and in the manipulations are such, that it is more satisfactory, at least for the present, to obtain static and dynamic balance on separate machines. In the following discussion of the two types of dynamic balancing machines of interest to the automobile industry, it will therefore be assumed that the body has previously been placed in accurate static balance.

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FUNCTIONS OF DYNAMIC BALANCING MACHINE

The functions of a dynamic balancing machine consequently are (a) the detection of the lack of dynamic balance; (b) the determination of the plane of unbalance, that is, the locating of the plane of the disturbing centrifugal couple in the body; and (c) the determination of the amount of unbalance, that is, the measuring of the magnitude and direction of the above couple.

In all dynamic balancing machines the body is so supported that the centrifugal couple due to the lack of dynamic balance becomes manifest in vibrations of the machine. A dynamic balancing machine therefore affords an excellent demonstration of what lack of balance

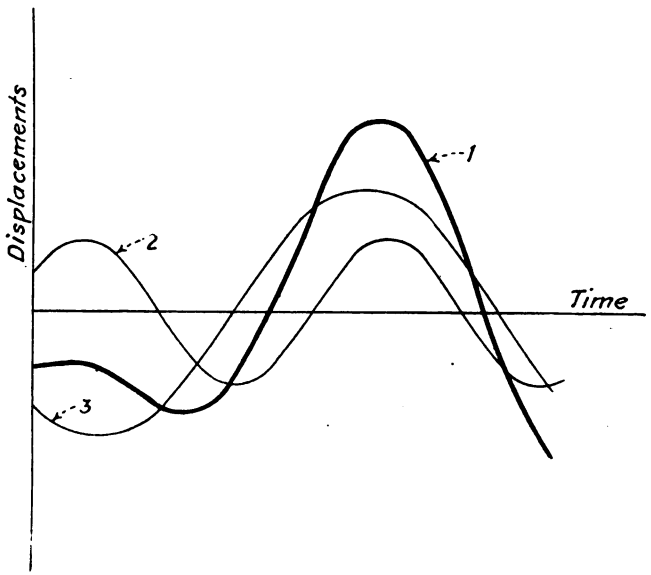

FIG. 11—COMPLEX FREE VIBRATIONS (NO. 1) CONSISTING OF TWO (NOS. 2 AND 3) HARMONIC MODES

can cause if the conditions are favorable. Usually the body while rotating is free to move in the horizontal plane, so that only the horizontal component of the centrifugal couple becomes active in exciting the vibrations. As will be shown, this component is periodic, and its period is the time in which the body completes one revolution. By making use of the phenomenon of resonance, that is, by rotating the body at such a speed that the period of the couple exciting the vibrations agrees with the natural period (or one of the natural periods if there are more than one) of free vibration of the system, even a small

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lack of dynamic balance becomes manifest in considerable vibration and is easily detected. In this manner a degree of sensitiveness not obtainable in any other way is obtained. The extreme sensitiveness of this process on the other hand requires that accurate static balance of the body shall have been obtained previously. If the static balance is imperfect, a free centrifugal force will be acting on the body in addition to the couple due to the lack of dynamic balance. This force, even if small, is itself capable of exciting considerable vibrations when resonance occurs and so would confound the results.

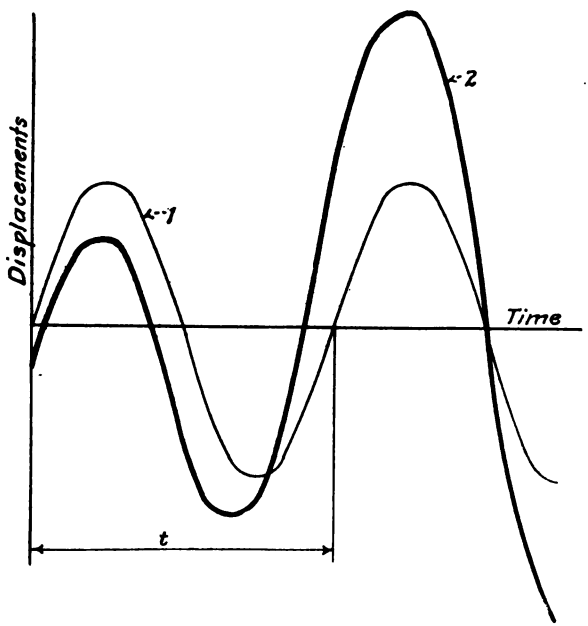

FIG. 12—COMPLEX VIBRATION (NO. 2) CONSISTING OF HARMONIC FORCED VIBRATION (NO. 1) SUPERPOSED ON FREE VIBRATION (NO. 1 OF FIG. 11)

The oldest of the vibrating dynamic balancing machines is the so-called floating-bearing machine, shown diagrammatically in Fig. 8. The machine derives its name from the peculiar arrangement of the bearings, which are held between springs, but are otherwise free to move in the horizontal plane. In order to reduce the friction each of the bearings is mounted on ball races. Rotation is imparted to the body by means of a belt.

The body being in perfect static balance, it will be subject when rotated to a centrifugal couple, consisting of the forces P. Let it be assumed that at the instant from which time is counted, the plane of

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the centrifugal couple is horizontal. A couple, as is known, is conventionally represented by a vector perpendicular to its plane of action. Thus, when XOX_1 is the plane of action of the couple at the beginning of time, it can be represented in magnitude and direction by the vector OC. After a lapse of t seconds, the body and with it the plane of the centrifugal couple has rotated through an angle ωt, when ω denotes the constant angular velocity of the body. The new plane of action of the centrifugal couple will be BOB_1, and the vector

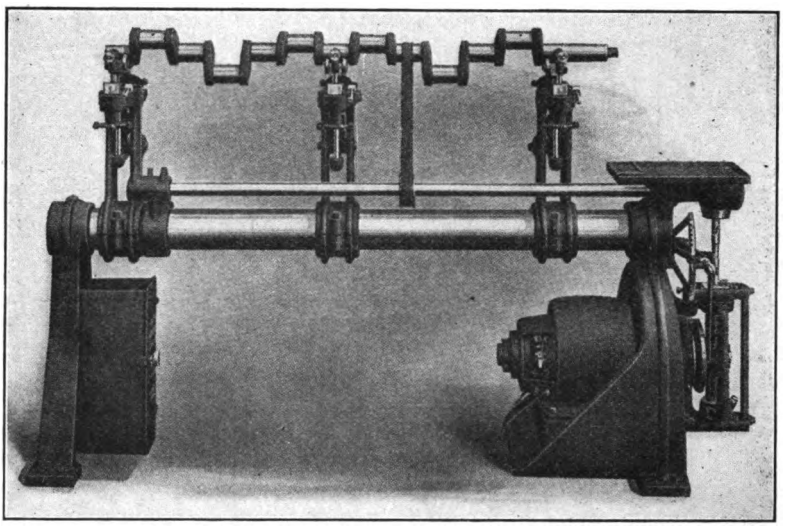

FIG. 13—NORTON BALANCING MACHINE (FLOATING-BEARING TYPE)

OC representing the former will now be directed along OA perpendicular to BOB_1. Angles XOB and YOA are equal to ωt. We resolve the centrifugal couple, when acting in the plane BOB_1, into two components, one in the horizontal and one in the vertical plane. This is equivalent to resolving the vector OC when directed along OA into the components x and y, which will be

$$x = OC \sin \omega t \text{ and } y = OC \cos \omega t$$

whereby x will be the vector representation of the vertical component of the centrifugal couple and y the vector representing the horizontal component. The latter tends to produce motion in the vertical plane, but it is prevented from doing so by the weight of the body. The horizontal component of the centrifugal couple ($y = OC \cos \omega t$) is therefore alone active, and since this component is periodic, it will excite vibrations of the body in the horizontal plane. The

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ability of the body to move in this plane is, however, twofold; it can oscillate about its center of gravity as indicated in Fig. 9, as well as vibrate parallel to itself between two extreme positions as in Fig. 10.

The actual motion of the body will therefore in general consist of a superposition of the two simple motions of Figs. 9 and 10. On account of the twofold freedom to move, there will be two distinct modes of free vibration with two distinct periods. Thus, if we hold the body in Fig. 8, say at one bearing, pull it forward and then let go, the body will execute a complex free vibration that will be the sum of two simple harmonic vibrations.

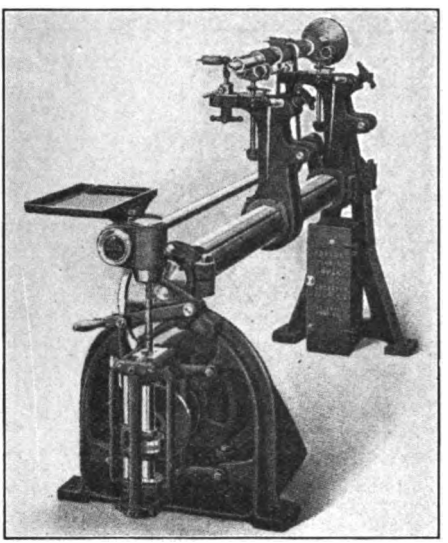

FIG. 14—END VIEW OF NORTON MACHINE

In Fig. 11, plotted with time as abscissas and displacements as ordinates, curve *1* will be the graph of the displacement of a point of the axis of the body from its position of rest as the body vibrates freely. The complex curve *1* is, however, the sum of two simple harmonic vibrations as depicted by curves *2* and *3*, the latter being designated as the modes of free vibration. Owing to mechanical friction and damping, the free vibration gradually vanishes.

As the body of Fig. 8 is started from rest vibrations in the horizontal plane occur simultaneously with the rotation, indicating lack of dynamic balance. These vibrations will consist of the complex free vibration (curve *1*, Fig. 11), on which is superposed a forced vibration, impressed on the body by the horizontal component of the centrifugal couple. When the body has run at constant speed for some time, say

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half a minute, the free vibration is damped out and a forced vibration remains in the horizontal plane while the body rotates.

The forced vibration, curve *1* of Fig. 12, is a simple harmonic; the time *t*, in which a point of the axis of the body completes a cycle, is its period and is equal to the time in which the body makes one revolution. At the least change in the speed of rotation, however, the free vibration reappears, and the displacement of a point of the axis of the body in the horizontal plane will occur according to curve *2* of Fig. 12, which is the sum of curves *1* of Figs. 10 and 11. The free vibration will again disappear after the speed is constant for some

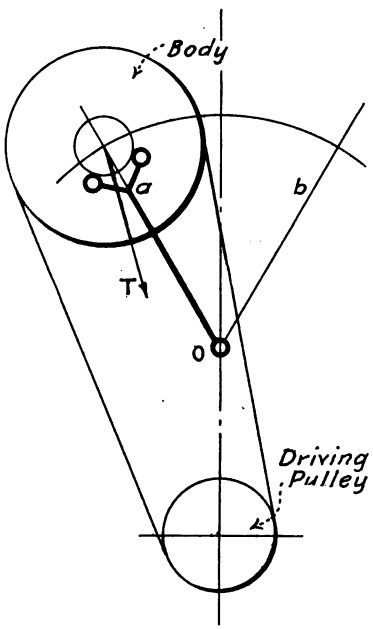

FIG. 15—SWING OF PENDULUMS IN FLOATING-BEARING MACHINE

length of time, to reappear at the next change in the speed of rotation and so on.

FLOATING-BEARING TYPE OF APPARATUS

With the effect of change of speed in mind we shall now discuss a floating-bearing type of apparatus, namely the Norton machine, shown in Figs. 13 and 14. The body to be balanced is carried on rollers situated at the ends of two or more vertically adjustable rods, which at their lower ends are supported

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on vertically adjustable cups. Where the rods pass through the stands, they are held at the front and back between rubber blocks, which provide the necessary elasticity to permit the rods to vibrate like vertical pendulums in a vertical plane, perpendicular to the axis of the machine. Rotation is imparted to the body through a motor-driven auxiliary shaft, to which the body is belted. The source of mechanical friction opposing the vibrations is mostly in the cup supporting the vertical pendulums and is due to the weight of the body

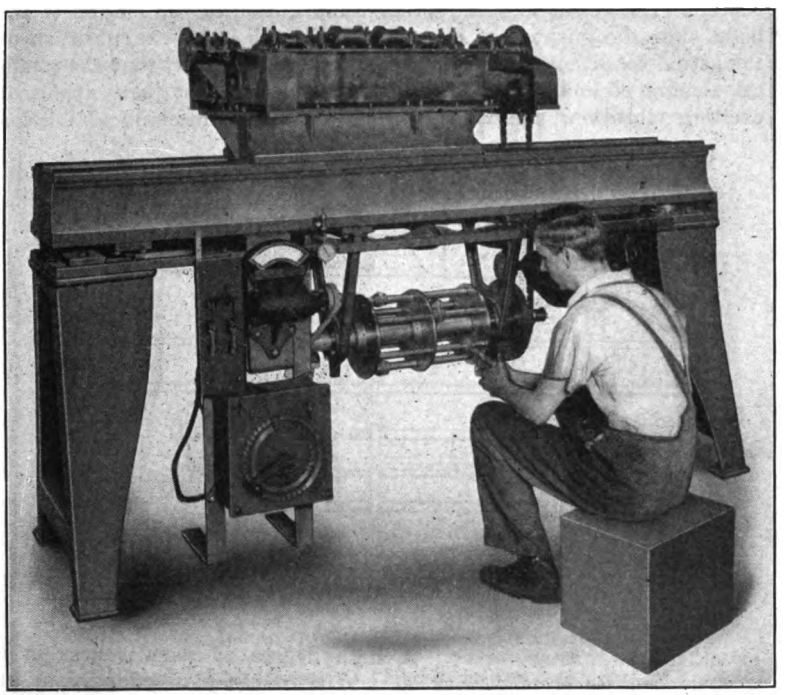

FIG. 16—AKIMOFF TYPE OF DYNAMIC BALANCING MACHINE

and the belt tension. This friction could be entirely eliminated by substituting for the rods flat springs, clamped at their lower ends. There is, however, one particularly objectionable feature in the general arrangement, and to bring out the point, we refer to the end-view of the machine in Fig. 15, showing the belt drive and also one of the pendulums in its extreme left-hand position. In the position shown, the resultant belt-tension T has a moment in respect to the point O. This moment must be overcome by the centrifugal couple of unbalance, and unless the amount of unbalance is sufficient to do so, the machine cannot show lack of balance when it actually exists. The

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adjustment of the belt tension is entirely within the pleasure of the operator; in fact, every time that the body is taken from the machine for a correction for balance and replaced again to test the effect of the correction, the belt has to be slacked off and readjusted, with no guarantee of just what the amount of belt tension is after each test.

The vibration of each pendulum between the positions *Oa* and *Ob* (Fig. 15), causes periodic lifting and lowering of the end of the body that it supports, as well as a periodic increase and decrease in the belt tension, owing to the variation of the distance between belt centers. The result is still further complication of the motion of the body. For the purpose of illustration, Fig. 15 is an exaggeration of the actual conditions. It must be appreciated, however, that the smallest amount of unbalance that can be detected is that just capable of exciting vibrations against the resistance due to mechanical friction

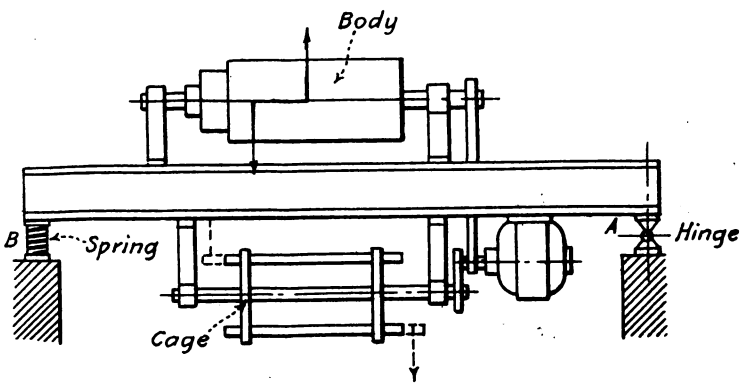

FIG. 17—SHOWING OPERATING PRINCIPLE OF AKIMOFF MACHINE

or other interfering forces. A high degree of sensitiveness in a machine can be accomplished only by avoiding painstakingly in its design all effects that tend to interfere with the free action of those forces that it is the object to detect.

In the Norton machine the vibrations of the pendulums are communicated to long pointers visible in Fig. 14. It sometimes so happens that one of the pointers is at rest while the other vibrates; this has given rise to the unfortunate notion that the body is balanced "at one end." It is hardly necessary to say that a body is either in balance or out of balance and that there should be no room for such expressions as "balance at one end." As long as the body vibrates, no matter whether all points of its axis move or one remains stationary, the body is out of balance.

Lack of dynamic balance having been disclosed by the vibrations, the next step consists in the determination of the plane of unbalance.

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For this purpose a stylus, placed on a level with the body, see Fig. 14, is gradually advanced and quickly withdrawn as it touches the body. Supposing that the stylus touches the shaft of the body in a single point; at the instant when this takes place, the point (call it *a*) of the axis of the body that is the center of cross-section passing through the marking point will be at its maximum displacement in the horizontal plane. An axial plane passing through the marking point and rotating with the body will be the plane of maximum amplitude for the point (*a*) of the axis. Whenever this plane coincides with the horizontal, the point (*a*) will be at its greatest amplitude, *provided, however, that only the forced vibration is impressed on the body.* The forced vibration, as has been stated before, is a simple harmonic

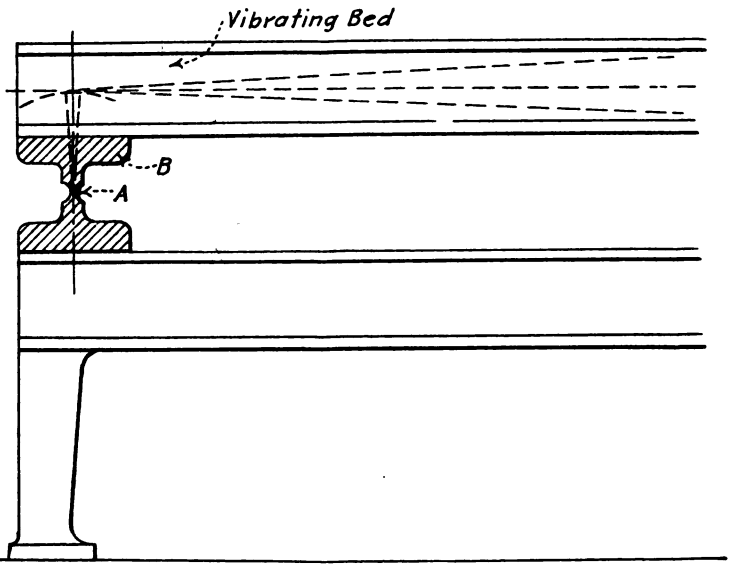

FIG. 18—HINGE USED IN AKIMOFF BALANCING MACHINE

wherein each cycle is a repetition of the preceding one (see curve *1*, Fig. 12). At the least variation in the speed of rotation of the body, the forced vibration will be superposed by the complex free vibration, curve *1* of Fig. 11, and the result will be a complex vibration as shown in Fig. 12, curve *2*, wherein each cycle *differs* materially from the preceding one. Should we, therefore, at a time that free vibrations are present, try to mark a point on the shaft, say for two or three succeeding revolutions, we would each time mark a different point.

In the floating-bearing machine, consequently, the plane of maximum amplitude for a given point of the axis of the body is only invariable when the speed of rotation has remained constant for some

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length of time, that is, after the free vibrations have died out. When such is the case, there is a definite angle of lead or lag between the planes of the centrifugal couple exciting the vibrations and the plane of maximum amplitude. This lead or lag is due to the damping forces, that is, in the Norton machine it is due to the molecular friction of the rubber blocks as they are compressed and extended by the motion of the pendulums.

Effect of Damping Forces

That damping forces are always the cause of a phase difference between the displacements and the exciting force is easily demon-

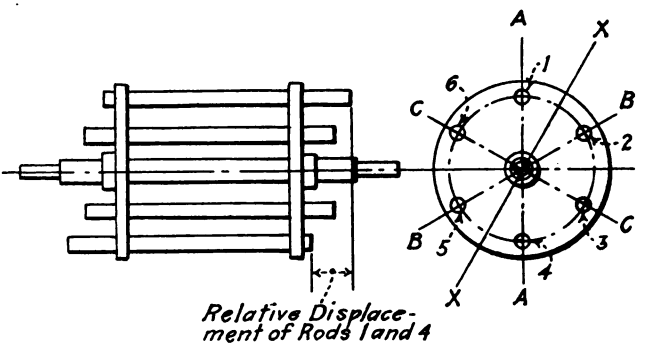

FIG. 19—CONSTRUCTION OF SIX-ROD CAGE ON AKIMOFF MACHINE

strated. Let a force P acting on a free body of mass m cause a vibration as expressed by

$$s = A \sin bt \tag{7}$$

whence its speed will be $v = ds \div dt = Ab \cos bt$ and its acceleration $a = dv \div dt = - Ab^2 \sin bt$. The damping force P_d is proportional and of opposite direction to the speed. Therefore $P_d = - fv = - Abf \cos bt$. The resultant force $P + P_d$ acting on the body is $P - Abf \cos bt$. But according to Newton, resultant force equals mass times acceleration; hence $P - Abf \cos bt = - Ab^2m \sin bt$; whence $P = - Ab\ (bm \sin bt - f \cos bt)$. When $\tan q = f \div bm$, this can be written as

$$P = \frac{Ab^2m}{\cos q} \sin\ (bt + 180 - q). \tag{8}$$

Comparing (7) with (8), it will be seen that there is a phase difference (in degrees) of $180 - q$ between the displacement s and the exciting force P. To calculate the angle of lead or lag is out of the question, but if we reverse the direction of rotation of the body, again mark a point with the stylus, and so determine the plane of maximum

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amplitude for the reversed rotation, the plane of the centrifugal couple will be the plane bisecting the angle between the two planes of maximum amplitude, provided: First, that the second point marked on the shaft lies on the same cross-section as the first. In practice the marking points generally lie on cross-sections ½ in. or so apart, introducing a slight error. Second, that the speed of rotation was exactly the same in both directions. Third, that at reversal of motion no change occurs in the mechanical friction, belt tension, or damping forces; as otherwise the angle between the planes of maximum amplitude and the plane of the centrifugal couple will not be the same for either direction of rotation, even though the speed had been the same in each case. Fourth, that the marking is done each time when free vibrations are positively absent.

It will be seen from the foregoing that the so-called high-spot method cannot yield uniform results, as too many conditions have to be satisfied in each case. In particular, when marking the body, there is not the least indication whether free vibrations are present. To start these it is only necessary that the driving motor change slightly in speed, and, as is known, all commercial motors are subject to speed variations following changes in the voltage or frequency of the current supply.

In the foregoing it has been assumed for the sake of simplicity that a single point is marked on the body. As a matter of fact a line of more or less length is obtained, whereupon it is arbitrarily assumed that it is the center of this line that determines the plane of maximum amplitude.

Determining Amount of Unbalance

Having located the plane of unbalance with a greater or less degree of accuracy, the next step consists in the determination of the amount of unbalance. Strictly speaking no such determination is attempted in the Norton machine, but in the plane of unbalance, by cut-and-try, weights are added or material is removed until vibrations of the body vanish. The objection to this process is that it can never be done methodically, and that it requires considerable time even in the hands of an experienced operator.

When the body is long and slender, as is a six-throw crankshaft, Fig. 10, the body is supported on a third pendulum as a guard against possible deformations. This arrangement is open to criticism, for unless the body remains supported on three points in all the possible motions that it can execute, the purpose of the additional support is defeated. Apparently the body can vibrate parallel to itself to and fro, and the support is still on three points. However, in the oscillations of the body, the two outer pendulums move in opposite directions, one toward and the other away from us. While the body oscillates, the middle pendulum can never move in such a manner that the supporting ends of the three pendulums are always in a straight line. If the centrifugal forces are actually sufficient to spring the shaft, they will

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do so notwithstanding the precautions to prevent just such a contingency.

IMPROVED BALANCING METHODS

The construction of the Norton machine today is nearly the same as it was over a decade ago. Since then improvements in the art have been made, notably by Doctor Lavaczeck in Germany. The highest development to date is attained in the Akimoff machine, which not only locates precisely the plane of the disturbing centrifugal couple, but actually measures—what no other balancing machine does—the magnitude of this couple and determines its direction. The machine is shown in Fig. 16, but its operation will be understood more clearly from the sketch in Fig. 17.

A bed is hinged at *A* and supported on a spring at *B*. The body to be balanced is placed on stands on the bed, which are adjustable lengthwise, and rotation is imparted by a motor hung underneath. The machine with body, motor, etc., can only vibrate about a horizontal axis passing through *A*. The motor drive is self-contained with the vibrating bed and body. In such a design there are absolutely no disturbing forces due to the drive. In addition all mechanical friction tending to impede the vibrations is eliminated. This is attained by the hinge shown in Fig. 18. The vibrating bed is supported on a T-shaped steel block *B*. A sufficient reduction in its cross-section makes *A* in effect an elastic hinge around which the oscillations take place. The elimination of all sliding metal parts at the hinge removes all mechanical friction. The sensitiveness of the machine is therefore of the highest possible order.

The couple due to the lack of dynamic balance is measured by the artificial introduction of a known counter-effect capable of causing the former to vanish. For this purpose the machine is provided with a cage (shown in Figs. 16, 17 and 19) which rotates at the same speed as the body. It consists of two or more disks, carrying an even number of accurately-finished rods (usually six or eight) diametrically opposite each other; each of the rods can be displaced in an axial direction while the machine is in operation. The large number of rods is provided only to facilitate the manipulations, as only two rods are actually required. Supposing then for the sake of simplicity that the cage—as in Fig. 17—carries two rods, normally opposite each other, in which position cage and rods form a perfectly balanced body.

When one of these rods is displaced axially relative to the other rod, as indicated by the dotted lines in Fig. 17, the static balance is not disturbed; but a centrifugal couple is introduced in the plane of the two rods, the magnitude of which depends on their relative displacement. The plane of the centrifugal couple of unbalance of the body is fixed within the latter. Owing to the train of gears that causes the body and the cage to rotate at the same speed, the plane of the two rods has a definite position relative to the body and therefore also relative to the plane of unbalance. If we so construct the cage

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that it can be advanced or retarded angularly, the plane of the centrifugal couple introduced by the axial displacement of its rods can be given any desired phase in respect to the plane of the centrifugal couple of unbalance. The couple artificially introduced by the cage can therefore also be brought in exact opposition with the centrifugal couple of unbalance.

Operation of the Machine

The body is placed on the machine with the cage in its neutral position. Upon imparting rotation to the body the machine bed vibrates, indicating lack of balance. The rods are then axially displaced and simultaneously the cage is advanced or retarded angularly, as the case may be, until the vibrations vanish. When this occurs the couple artificially introduced by the cage must be exactly equal and opposite in its action to the centrifugal couple of unbalance in the body. The plane of unbalance will therefore be the plane passing through the axis of the body and parallel to the plane of the two rods. To mark this plane on the body, we turn the body by hand until the plane of the two rods is vertical, when the vertical plane passing through the axis of the body will be the plane of unbalance. The direction of the centrifugal couple of unbalance is evident from the relative position of the rods, since it must be oppositely directed to the couple introduced by the cage. The amount of unbalance, that is, the magnitude of the centrifugal couple of unbalance, is at once determined by measuring the axial displacement of the rods relative to each other and from the known weight of the rods per unit length.

Changes in the speed of the driving motor affect the body as well as the cage in exactly the same manner. As long as free vibrations are present, no possible adjustment of the cage can cause the vibrations of the machine bed to vanish. Therefore, neither changes in the speed of the driving motor, nor free vibrations from whatsoever causes, can affect the accuracy of the results. This ingenious method excludes all possibility of error, for no reliance is placed on marking points and no rotation in two directions at exactly the same speed is required. When the cage is so adjusted as to cause the vibrations of the machine bed to vanish, the position of the rods in the cage becomes at once the indicator for the plane, for the magnitude and for the direction of the centrifugal couple of unbalance, leaving nothing to chance or to cut-and-try methods.

This method has still another advantage; it permits of a well organized and accurate system for the removal of material in the plane of unbalance. The points at which material can be removed from each body are limited. Once these are determined, tables are furnished with the machine, so that the operator, by merely reading the axial displacement on the graduated rods, can find at once the size of drill to be used and the depth of hole to be drilled.

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Introduction of Artificial Couples

A cage with two rods can be used for cylindrical bodies, but is not suitable for such bodies as three-plane crankshafts. The material in such shafts can be removed only at the crank webs, that is, virtually in three planes only. For such purpose a cage with six rods is required. Axial displacements of the rods *1* and *4*, *2* and *5*, *3* and *6* (see Fig. 19) introduce centrifugal couples in the planes *AA*, *BB* and CC respectively. If at the beginning the cage is adjusted so that the plane *AA* is parallel to one of the planes of the crankshaft, *BB* and *CC* will necessarily be parallel to its two other planes, and by giving axial displacements to the rods we can artificially introduce centrifugal couples in each of the three planes of the crankshaft. This is particularly valuable in case the plane of unbalance happens to be so situated between two of the crankshaft planes that no material therein can be removed.

Let us suppose, for instance, that *XX* (Fig. 19) is a plane parallel to the plane of unbalance, so that in order to cause the vibrations of the machine bed to vanish a couple must be introduced by the cage in the plane *XX* opposed to the centrifugal couple of unbalance. This can be accomplished by giving axial displacements to the rods *1* and *4*, as well as the rods *2* and *5*, thus introducing couples in the planes *AA* as well as *BB*. By adjusting these displacements properly, the resultant of the two couples can be made to act in the plane *XX* and to be of the proper magnitude and direction to neutralize the centrifugal couple of unbalance. The correction for unbalance will then have to be applied in those planes of the crankshaft parallel to *AA* and *BB*. When the location of the plane of unbalance is such that no material can be removed, a multi-rod cage permits the location of two or more other planes, wherein corrections for unbalance can be so applied that their combined effect is the same as if these corrections had been applied directly in the plane of unbalance. In any other dynamic balancing machine, if the plane of unbalance proves to be a plane from which no material can be removed or to which it can be added, cut-and-try methods must be used to determine the two or more other planes wherein corrections are possible.

On the Akimoff machine it is easy to check to see whether accurate static balance has been obtained previously. This is done as follows: The cage is first so adjusted that the body can rotate without vibrations of the machine bed, next the body on the machine is shifted say some 10 or 12 in. toward the hinge without changing the relation between body and cage, and rotation is again imparted to the body. If it is in static balance, no vibrations will occur; if not the machine will disclose the fact by vibrating. In the latter case a free centrifugal force will act on the body in addition to the centrifugal couple. The change in position of the body does not affect the couple, but it causes a change in the lever of the free centrifugal force with respect to the hinge, resulting in renewed vibrations.

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Finally, a most valuable feature of the machine is the fact that it permits the testing and correction of a body for unbalance in its natural position and in its own bearings. Thus a crankshaft can be balanced in its own crankcase, as shown in Fig. 16. This in turn suggests another important field for the machine, which should prove to be of particular value to the automobile industry. The machine can be readily adapted to receive a complete automobile engine and from its manifestations valuable data can be obtained in regard to the effect of vibration caused by the reciprocating parts.

DISCUSSION

F. HYMANS:—We must necessarily be fully acquainted with the reactions that take place when a rigid body rotates about a fixed axis. These are simple and easily remembered. They are: If an unbalanced body rotates about a fixed axis it reacts on its shaft with a free centrifugal force, which has its point of application in the center of gravity of the body; and with a centrifugal couple, acting in an axial plane, which is different from the axial plane that contains the free centrifugal force. Balance in a body can be obtained only in two steps, namely, by static balance and by dynamic balance. Static balance corrects for eccentricity of the center of gravity of the body. It can be obtained by adding or removing material in at least one single point of the body. If the body is statically balanced there still remains at rotation a centrifugal couple. Dynamic balance serves to eliminate the centrifugal couple; it can be obtained by adding or removing material at two different points, situated in the plane of the centrifugal couple, one above the axis and one below the axis of rotation. In short, then, in an unbalanced body we must compensate for a free force and for a couple by means of corrections in at least three different points.

The difficulties in the design of a dynamic balancing machine are perhaps best illustrated by the fact that there are to-day only three types that have been developed into practical machines. The oldest of them is the floating-bearing type, represented in this country by the Norton balancing machine. About three years ago Doctor Lavaczeck, a German, placed on the market a dynamic balancing machine which was a decided improvement on the floating-bearing machine. The blue ribbon, so to speak, returned to this country, however, when Mr. Akimoff invented his ingenious machine. I have also devoted several pages to the Norton machine since improvements are never so well appreciated as when contrasted with the older methods.

DELMAR G. ROOS:—We have had an Akimoff machine in operation now for something over four months, running alongside a Norton machine. Our reason for adopting this type of machine was because of the difficulties that we encountered in the floating-bearing type.

One of the difficulties with the floating-bearing type of machine

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grows out of the fact that since the phase displacement between the impressed forces and the actual displacement of the body occurs at very low speed, the body actually tends to rotate with the heavy side in and the light side actually flies out. The workman is never certain whether the heavy or the light side is running out; at one time he may be marking the light side and another time the heavy side. At the best it was a tedious process, requiring a man with a certain amount of balancing intuition. If he happened to go on a strike or get lost we ceased balancing crankshafts for a while until he came back. We therefore welcomed the advent of a machine on which such a thing as an accurate balance could be obtained in a scientific way.

We split up the operations into four divisions. First, one man statically balances the crankshaft and he is able to balance all our crankshafts for us statically. Of course, our output is not large, and the number of shafts we have to balance is nowhere near the capacity of the dynamic balancing machine.

We find that one man can indicate the plane of unbalance and locate the points at which we should drill the crankshaft in order to secure proper dynamic balance in fifteen minutes at the most. In the second operation the shafts are balanced in the crankcase, scraped in in the bearings, just as they go in the finished engine. The third operation is to drill the shaft. The fourth operation is to check the dynamic balance again.

This latter we do not find necessary because the machine does the work so well. The actual operation of securing dynamic balance consists of putting the crankcase on the machine with the crankshaft in it. The speed of the machine is controlled by a rheostat. There is a speed indicator, also a small indicator for indicating the amplitude of vibration of the bed of the machine. The operator varies the speed of the machine until a speed of resonance occurs and the vibration is at its maximum. This is very easily determined.

In this particular machine it is in the neighborhood of 400 r.p.m. When that speed has been reached he then begins to correct the vibrations of the machine with the balancing gage. He does it with the horizontal bars of the gage. These bars are in phase with the three planes of the crank-arm, each pair of bars corresponding to a pair of crank-arms in the same plane.

We find that it is always possible to correct the dynamic balance in either one of two or three planes. Sometimes it can be done in one plane but always in two. We have never found it necessary to correct in three planes.

After the operator has slid these bars until the amplitude of vibration has reached practically nothing on the indicator he stops the machine and reads the displacement of the bars in inches. These bars are of known weight and are marked off with a scale so that the displacement can be read easily. The operator is supplied with a table

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that tells him where to drill. Say, for instance, the plane of unbalance is found to correspond to crank cheek No. 1, the table would tell him to drill crank cheek No. 1 and crank cheeks Nos. 8 and 9, we will say for a ½-in. drill to a certain depth. He has no choice in the matter and he cannot go wrong. He passes the shaft to another man, who drills as directed. The drilling is always done in the center-line of the crankpin. The results obtained by the machine are really remarkable in smoothing up the action of the engine.

The machine is so accurate that it becomes necessary in order to obtain the full benefit of it to balance all the reciprocating parts within close limits. We balance our connecting-rods by machining them all over and holding the weight to plus or minus 1/16 oz. and holding the center of percussion of the rod within just as close limits as a man can measure. We also hold the piston within these limits and the result of all these things made possible by this machine is to make the operation of our engines more smooth.

I disagree with the remarks in Mr. Hyman's paper relating to the pin type of balancing machine, because it is a good and practical way of balancing flywheels. The reason why is clearly explained in his paper, namely, that as a disk-like body is approached more nearly running balance and static balance almost coincide. I presume that is why we are able to get a very good running balance on our flywheels in this way. We are preparing fixtures so that we can balance our flywheels on the dynamic balancing machine.

N. W. Akimoff:—In developing the dynamic balancing machine my main object was to produce something that would be of immediate, tangible value to the automobile engineer and manufacturer. The machine was worked out by pure deduction, that is, having the main object in mind I tried to solve the problem in a logical analytical way, and not by piecing things together or assuming that this or that was so and so. However, the machine as finally designed was found to be of such simplicity that any workman could easily grasp the method of operation. Then by absorbing the working data and tables all mental work on his part could be eliminated. Such tables are of greatest value and of course should form part of each machine.

A very refined static balancing machine can be made on a practically similar principle, although for crankshafts it appears as though plain balancing *ways* would be sufficient; at any rate the static balance is the main part of the problem, the longest and the most tedious one. Dynamic balance proper can be obtained quickly and with little effort, especially if fixtures have been provided for drilling holes or grinding metal off without any delay.

It should be thoroughly understood, however, that such a machine can accomplish only dynamic balance proper; that is, elimination of the centrifugal couple. There are several other sources of vibrations, such as lack of balance in the reciprocating end of the mechanism,

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structural weakness of the shaft or the underframe, and last but not least, the torsional vibrations of the shaft.

While the subject is exceedingly difficult it is capable of rational treatment. The substance is this: according to the simplified method, which I have worked out, a crankshaft possesses not an infinite number of degrees of freedom, but just seven degrees (speaking of a six-cylinder shaft) and consequently also seven main modes of free torsional oscillation. These modes are not related in the ratio 1:2:3, etc., as one may think at first, but can be derived from a most complicated so-called detrimental equation of the fourteenth degree.

The research engineer's problem is to so proportion the cheeks and other elements as to secure immunity from vibrations in the interval between the two severest modes; it is possible to do so, although it takes about four to five weeks to work the thing out. All this is a special problem, which I am mentioning here only to caution against confusing the effect of torsional vibrations with that of dynamic unbalance, which one would be apt to do.

Another thing on which I cannot insist too much is that providing a shaft with counterweights and securing dynamic balance are two entirely different things. Many engineers seem to think that a shaft with counterweights is necessarily a balanced one; of course this is absolutely wrong, as is also the belief that excellence of material or workmanship is a remedy against dynamic unbalance. A forged flywheel or a piece of straight shaft, turned and ground, may require correction for dynamic balance, let alone a complicated affair like a six-throw crankshaft.

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REMARKS ON DYNAMICS OF THE AUTOMOBILE

By N. W. Akimoff
(Member of the Society)

Abstract

The author believes that an incompatibility exists between the results achieved in this country by the growth of the automobile industry and the almost complete lack of rational data on the most essential elements of kinetics relating to the modern automobile.

He submits considerations that can be used in establishing a rational theory of spring suspension in general. A few words are devoted to the first principles of dynamics of springs, to damping, kinematic features of harmonic motion, energy consumption and shock absorbers.

An introductory problem, involving an imaginary one-wheel "elemental car", meant for purely inductive purposes, is then analyzed. Finally the main problem is presented in the form of an analysis of a skeleton-car, spring-suspended and simplified as much as possible.

INTRODUCTION

The technical literature of the world is not superabundant as regards the subject of dynamics of the automobile. A great deal of work has been done by French engineers, especially by M. Marie, on dynamics of railway rolling stock, but there the problem is much different, and in fact much easier than that relating to automobiles. In looking over various transactions of automobile-engineering societies the author finds that they contain only *opinions* on such important questions as suspension, kinematics of vibratory motion, friction in springs and absorbers. These opinions would no doubt be of value were it not for the fact that they are about evenly divided into two classes, the claims of which are diametrically opposed.

It does not appear that any definite conclusions have been reached regarding friction, for instance. Good authorities claim positively that friction in springs is absolutely necessary, while other equally prominent engineers deny just as positively the necessity for such friction and suggest abundant lubrication of leaves as a remedy for hard-riding springs.

A definition of "easy riding" has never been agreed upon. Some engineers feel that the *amplitude* of oscillation should be reduced; others that the *period* should be kept down. The author will try to show that it is the numerical value of linear up-and-down acceleration that makes riding hard or easy.

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Shock absorbers constitute another point on which no verdict has been reached so far. Some of the best engineers oppose this or that type of absorber; yet, under certain conditions, any impartial observer must admit that a car provided with absorbers actually rides better.

When it comes to the next step, the all-important question of suspension, we have no theories and no systematic tests; just a few isolated reports that no logic can cement into a solid principle on which to work. Does the cantilever spring ride better? Does a long wheelbase make the car easier riding? If the cantilever spring rides better, this is not due to any of its characteristic properties, such as greater deflection; but can be explained by a seemingly secondary circumstance, the method of its connection with the frame. The wheelbase has only an indirect effect in solving the problem of easy riding.

SOME PROPERTIES OF SPRINGS

A spring can oscillate about its position of rest, with a certain period (meaning time for motion from say middel position to one extreme, then to the other and back to starting point $T = 2\pi \sqrt{\delta/g}$ where T is the period* in seconds; $2\pi = 6.28$; δ is the initial (static) deflection, expressed in feet; $g = 32.2$ ft. per sec. per sec.

Such an oscillation will be a damped one and will have a tendency to die out after a certain interval of time. The damping is due to friction of various kinds. It is not necessarily due to air friction, because a vibrating rod (or reed) will come to rest in a vacuum; not necessarily due to actual rubbing friction alone (as in leaf springs), but, to a considerable extent, to some sort of a molecular action, always resulting in a temperature increase, and which can be shown to be approximately proportional to the velocity.

But what most engineers do not realize are the following properties of damped oscillations: if the friction is constant, the amplitude of motion decreases, but *the period remains unchanged* (barring, of course, the extreme cases of abnormal damping). If the damping is proportional to velocity, then the period is only *slightly* increased; so little, in fact, that here, too, it can be considered unaffected; while the amplitude decreases.

All this refers to so-called free vibrations of a spring, plucked or given an impulse and let go. A spring subject to any periodic action, actuated, for example, by some sort of a connection with an unbalanced engine, will vibrate precisely at the rate of the latter. This constitutes what is known as forced vibration. Just as soon as it is freed from the influence of the periodic force the spring quickly converts the forced vibration (with a strange period) into a free

*An instantaneous method has been proposed by the author for finding the period in one setting of the slide-rule; see *American Machinist*, Aug. 24, 1916, p. 318.

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vibration of its own natural period, depending solely upon the initial stretch it had under its load. All this holds good only for such cases as that of a spring arranged vertically and supporting a weight. Under no circumstances can the formula be applied to a case of a body rocking about one end and spring-supported on the other. This might introduce an error as great as 100 per cent or

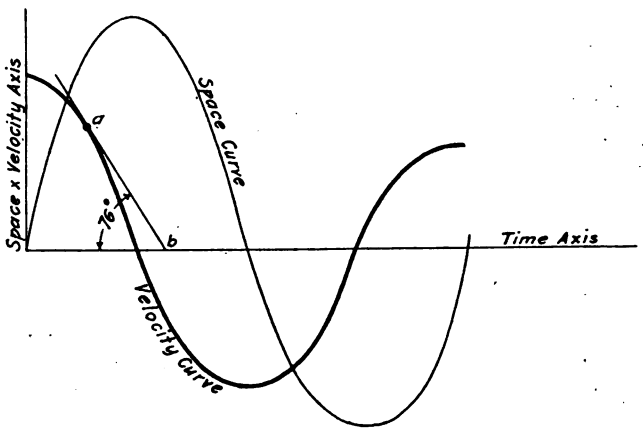

FIG. 1—METHOD OF DETERMINING WHEN PASSENGER AND SEAT WILL SEPARATE

more, and an entirely new formula would have to be derived. This has been actually verified by the author in connection with a dynamic balancing machine that he originated. (See author's book, "Lagrange's Equations.") To date no one seems to have noticed the absurdity of applying the plain pendular formula to questions of automobile suspension, involving rocking or pitching.

SEPARATION OF PASSENGER AND SEAT

From the kinematics of vibrating motion we can find under what conditions the passenger will be thrown from a seat vibrating according to a plain pendular law. The author suggests the following simple method: assuming (Fig. 1) that the time-velocity curve has been calculated, the axis of time being laid off to a scale eight times that of velocities, the passenger will leave the seat at such a point that the tangent *a-b* will form with the axis *t* an angle of 76 deg. If no such tangent* can be drawn, the passenger will remain in contact with the seat.

*Such a tangent would mean that the velocity of the seat is less than that of a tossed-up body; the latter velocity, as is well known, is, $V_o - 32.2t$, where V_o is the initial velocity. This represents a straight line forming an angle with the time axis whose tangent is 32.2. If the scales of time and velocity are the same, this angle would be very nearly 90 deg. For this reason it is best to increase the scale of time.

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The passenger's weight (pressure) on the seat will depend entirely upon the acceleration during his movement up or down. The numerical value of this varying weight will be $P\ (1 \pm \alpha/32)$, where P is the original weight in pounds, and α is the acceleration in feet per second per second, the sign + referring to upward and the sign — to downward motion. The passenger's muscles are constantly adjusting themselves to the continually varying weight, according to this simple formula, and it is precisely this constant relaxation and contraction that makes hard riding so objectionable. Large amplitudes alone do not matter; long periods help materially, since they decrease the acceleration. The maximum value of acceleration can be figured from

$$\alpha_m = 0.011\ a\ n^2$$

where a is the maximum swing (amplitude) in feet and n is the number of oscillations per minute.*

Mention should be made here of an apparently strange, although easily accounted for, behavior of springs as shock-transmitting elements. Fig. 2 represents a weight W supported by an ordinary spring scale B. A small weight w rests upon the removable platform p, being connected to the larger weight by the string s. The experiment consists in adjusting the relative weights and the heights of w and W so that the dropping of the former from p will not affect the scale B. This can be readily accomplished if the string is unyielding enough. We now replace s by an elastic string or a light coil-spring; the same weight w dropped from the same height p will now affect the pointer of the scale B. The practical explanation is that in the first case the impulse is wholly absorbed (and destroyed) by the string s; it has no time to reach the upper end of W. In the case of the coil-spring the falling weight is allowed to perform a certain amount of work; the tension is at once equalized all along the spring and has time to reach the scale B. Conditions can therefore be imagined readily such that a coil-spring shock-absorber would transmit to the body an impulse that would not be felt otherwise.

The objection to frictional shock absorbers (it applies also to the friction of spring leaves proper) appears to be that in climbing up a bump the action of the spring is retarded, thus throwing a certain amount of extra load on the tire (and the spring), already overloaded owing to the upward impulse due to the obstacle. In allowing the compressed spring to come gently to its normal position, the absorber performs its useful work, provided the action is not delayed too much. This delay would indeed decrease the adhesion, and another bump could follow the first; a paralyzed spring would not act well on the latter.

When the wheel drops into a pocket or depression of any sort we

*Every pendular motion is expressed by some such law as $s = a \cos \omega t$, where s is the deflection from neutral position; a the amplitude; and ω the angular velocity of the representative point describing a corresponding circle. Deriving this time we have the acceleration—$d^2s \div dt^2 = a\omega^2 \cos \omega t$, the maximum value of which is $a_m = a\omega^2 = a\ \pi^2\ n^2 \div 30^2 = 0.011\ an^2$.

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have the reverse conditions; the absorber retards the descent of the wheel (thus decreasing adhesion) and does its best work in restoring the wheel to its normal position, although here, too, the action should not be delayed too much. It is evident that these actions are contradictory. What we would like to have is an absorber that is inert when the wheel goes over a bump and active in coming down; also inert when the wheel goes down into a hole and active in restoring

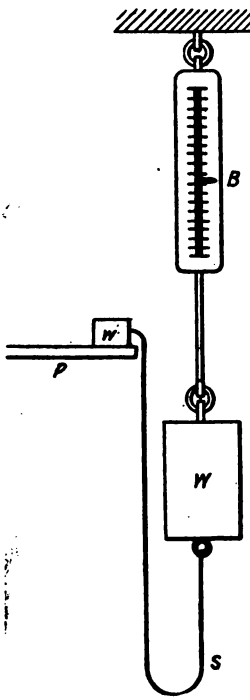

FIG. 2—DEMONSTRATING SPRING BEHAVIOR

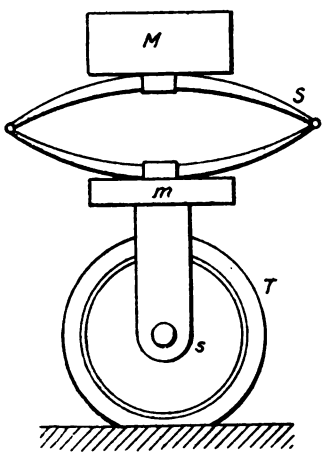

FIG. 3—ELEMENTAL ONE-WHEEL SUSPENSION

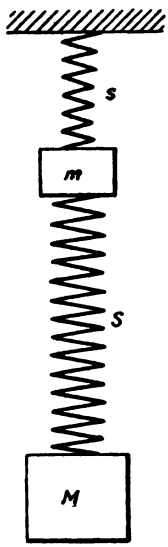

FIG. 4—TYPE OF DOUBLE SPRING SUSPENSION

it to its normal position. It does not appear possible for any absorber to answer these requirements. The absorber does its best work on a comparatively even road, in preventing the rocking (pitching) oscillations that on some cars are exceedingly annoying and seem to be set up without any reason whatsoever. This same result can be obtained by a more rational suspension.

The author recalls a most curious fact; a well known low-priced car of 1915 model had its suspension so well proportioned that any one could easily believe that an unusually efficient absorber had been provided to secure such beautiful riding qualities. The best plan would have been to leave well-enough alone; instead the makers "im-

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proved" the suspension and the next year's model was decidedly inferior so far as riding qualities were concerned. This shows that it is possible to secure good suspension without any absorber whatever, and also how elusive the problem of suspension seems to be.

What surprises the author most is that the fight between the champions and the antagonists of absorbers is progressing on altogether wrong grounds. Just how is the car body apt to oscillate under different conditions? Surely not as if the car were sawed in half, transversely, each half moving *up* or *down* and being taken care of by its own spring and its own absorber. Just how the problem should be approached will be shown later.

It is not my intention to present a complete analysis of the influences of a set of impulses on a car. This not only would be difficult, but also quite meaningless, because no general deductions could possibly be made from any theories advanced on so broad a subject. But regardless of all theories it is always possible to imagine two or three successive holes in the road of such shape and so located that they will break any spring with corresponding effect upon the car; and such that their effect cannot be possibly counteracted by any absorber or suspension.

What actually can be done is to consider various modes of free oscillations of the body. An impulse sets up free vibrations in the car; and often on an apparently well-kept road a car will not ride well. It is as if some invisible influences were synchronizing with the "favorite" free oscillations of the car to produce the worst results. This question of free periods of a car has been so completely overlooked that it will be well to consider a specially conceived problem.

ELEMENTAL SUSPENSION SYSTEM

Imagine an elemental "car" Fig. 3, consisting of one wheel s, provided with a pneumatic tire T. The platform m represents the upsprung weight, M is the sprung weight, S being the spring supporting it. If the platform m is steady, the natural period of the up-and-down oscillation of M will be $T = 2\pi \sqrt{\Delta/32}$ where Δ is the initial static deflection of the spring S under its load M. The tire itself is to a certain degree elastic and is capable of oscillations of its own. By reference to reliable tests* it can be ascertained that an inflated tire gives the same *straight line* in the load-deflection diagram as does any spring; also, the oscillations of a tire possess the same character of damped *periodic* motion as any other elastic body; the only exception being that the tire is much stiffer than the spring, say 15 times. For example, a load of 100 lb. will then deflect the average spring 15 times as much as it will the corresponding average tire. It is not the numerical value of this ratio that interests us just at present, how-

*See *La Technique Automobile et Aérienne,* Jan. 15, 1914, p. 12, and Feb. 15, 1914, p. 32.

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ever, but the fact that this elemental system is *doubly elastic* or possesses two *degrees of freedom*, as a mathematician would say. This at once suggests the similarity of the problem to the well known problem in dynamics of the double spring, Fig. 4, which has been worked out elsewhere.

The conclusions are that there will be two independent modes of vibration in such a system. One mode will comprise simultaneous oscillations of both weights, possessing the *same period*, both moving

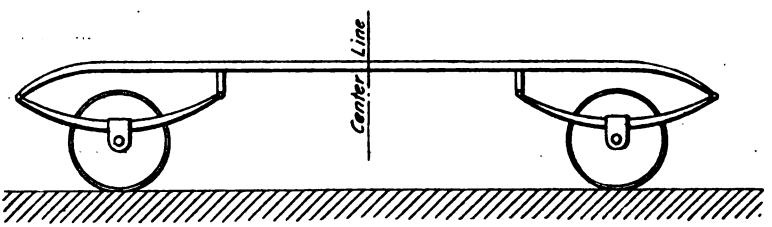

FIG. 5—SKELETON CAR ASSUMED TO POSSESS ONLY LENGTH AND HEIGHT

up or down at the same time, although the amplitude of the lower weight M will be greater than that of the upper weight m. The second natural mode will be such that both weights move *in opposite directions*, although with the same period, but through a much shorter amplitude than before. Neither the short nor the long period is the same as they would be if the weight M alone vibrated on its spring S. This shows how inadequate is the pendular formula if directly applied to the problem of natural oscillations of the car, even of the simplified car we are considering. In general the motion of the weights, Fig. 4, will be compounded of the two typical modes just mentioned, and might appear exceedingly complicated, although in reality it consists of two simple pendular motions superimposed.

An automobile can vibrate in a number of different ways, the main modes of oscillations being plunging (straight oscillations up-and-down), rolling (about a longitudinal axis) and pitching (about a transverse axis). The secondary vibrations are yawing, fore-and-aft swinging and transverse swinging. In order not to complicate the problem too much, we shall consider a skeleton car, Fig. 5, possessing but two dimensions, length and height. The only chief modes of oscillation will be plunging and pitching. The tires will be supposed to be non-elastic, as the contrary assumption would complicate the problem greatly, adding several degrees of freedom. The springs are both alike and the body is assumed to be symmetrical with respect to a vertical axis through its center. The mathematical operations by which both free periods of oscillation can be found is given in the author's book on Lagrange's Equations, in which chapter V is devoted to oscillations and to free periods. In fact Lagrange's method

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of solving problems of dynamics in a nearly automatic manner is especially valuable in its application to the problem of vibrations of all sorts.

The periods for the specific problem have been found to be: For plunging, $T_p = 2\pi \sqrt{\delta/g}$; for pitching, $T_p = 2\pi \sqrt{\delta/g} \sqrt{2k^2/l^2}$, where δ is the initial (static) deflection of each spring under its load; g is 32.2; k the radius of gyration about the center of oscillation; and l the wheelbase.

DEDUCTIONS FROM PERIOD FORMULA

The plunging period, aside from giving an idea as to its relation to the pitching period, is of no special interest. But the formula for pitching period suggests:

First: The weight proper of the car does not enter directly and is only implied by the initial static deflection of the springs. This deflection however is quite as characteristic of the springs as it is of the weight.

Second: The distribution of the weight appears to be of importance, as is evidenced by the radius of gyration k, to which the period is directly proportional. In other words, to secure easy riding (slow period of pitching) the loads should be placed as far as possible from the center of the car. The mere fact that they give the same deflection does not in itself preclude the possibility of entirely different effects due to load distribution.

Third: The wheelbase should be kept as short as possible, because the period is inversely proportional to its length. This of course does not mean that it should be reduced to ridiculous proportions; the practical requirements of safety, static stability and appearance will at once fix limits in this respect; but these will be *lower* limits, for each type of car. It can likewise be shown that the linear up-and-down acceleration of the extreme points of the car, such as the rear seat, is practically proportional to the third power of the wheelbase; hence another reason why this dimension should be kept short.

Fourth: If a car with a large wheelbase rides easily, this is not due to the wheelbase itself, but to the fact that its larger value means a larger car, in general, a larger body and possibly a greater radius of gyration. It is possible to imagine a case in which the wheelbase has been increased and the weight distribution and the radius of gyration, in fact the whole body, has been left unchanged. Such a car, other things being equal, will not ride so well.

Fifth: As regards the cantilever-spring arrangement the true explanation seems to be easy enough. Assuming that we have two identical cars, the wheelbase, initial (static) spring deflection and everything else being the same, one provided with cantilever springs and the other, say, with full-elliptic springs. If the cantilever arrangement gives better riding qualities, the reason lies in the fact that the spring is fastened more closely to the center of the body,

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thus giving the same effect as would a reduced wheelbase, that is, a slower period of pitching.

AUTHOR'S CONCLUSION

Put into concrete form, these deductions would result in a modified and rational design of the suspension. A suspension built along such lines will include much better kinematic means for allowing the car to swing in the manner required, than seems to be used in the majority of cars today.

The shock absorbers would have to be modified to act in accordance with these requirements. They would have to take care of the pitching action, which in a rational design will have been made as slow as possible. Efforts to modify other effects of the shocks would have to be dropped. No shock absorber can help here, except in particularly special cases; the reasons have been previously outlined.

In conclusion, lest any misunderstanding should arise, the author will once more emphasize his request that the *spirit* of this paper and not separate lines or words be absorbed and commented upon. The author does not deny the fact that some of the easiest riding cars have extremely long wheelbases; others, although having a short wheelbase, ride unbearably. He does not mean to say that a wheelbase of 120 in. will necessarily give a better riding car than one say, of 135 in., but he does believe that it is possible to secure and to account for such a result.

DISCUSSION

PROF. S. E. SLOCUM:—In my opinion, the important features of this paper consist in two statements:

The first is to the effect that the quality of hard or easy riding is dependent on the vertical acceleration as given by the formula

$$a = 0.011\, a\, n^2$$

where a denotes the amplitude and n is the frequency of the motion. Since the frequency n is the reciprocal of the period T, this relation may also be written

$$a = 0.011 \frac{a}{T^2}$$

From this it is apparent that to secure easy riding qualities it is desirable to make the amplitude of the motion small, but still more essential to make the period large.

The second important statement is that the principal period is given by the formula

$$T = 2\pi \sqrt{\frac{g}{\delta}} \sqrt{\frac{2k^2}{l^2}}$$

$$T = C \frac{k\,\delta^{1/2}}{l}$$

where C denotes the constant part of the expression. As this formula

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is the gist of the whole discussion, it is a matter of regret that at least the outline of its derivation is not given.

It seems clear however that certain general conclusions can be drawn from these formulas as to what constitutes an easy riding spring. For example, a full elliptic spring will have twice the amplitude of a half-elliptic spring under the same conditions, but as the static deflection δ is also twice as great for the full as for the half elliptic, the linear acceleration a is the same for either type. A cantilever spring, however, must be twice as strong for the same load as an elliptic spring of double the length, and is therefore correspondingly stiffer. This tends to reduce the value of the amplitude a, although this effect is offset to a certain extent by a similar reduction in the static deflection δ.

The most important factor in securing easy riding is evidently the radius of gyration k. Although this quantity is not clearly defined in the article under discussion, I understand it to mean the radius of gyration of the total live and dead load with respect to the instantaneous center of oscillation at any instant. This evidently increases rapidly with an increase in weight of car and passengers. Also for a heavy type of car, the weight of passengers is relatively smaller as compared with the total weight than for a lighter type of the same carrying capacity, and consequently the riding qualities of the heavier car are more uniform under various conditions of loading.

As regards shortening the wheelbase, I am reminded of the anecdote of the optimistic agent who claimed that the riding qualities of his car were 100 per cent better than those of cars of other makes because the wheelbase was so short that all four wheels took the bump simultaneously.

The actual distance between axles is determined largely by the type of body and engine, but, as Mr. Akimoff points out, the effect of a shorter wheelbase can be secured by using a cantilever rear spring attached to the chassis in front of the axle instead of directly over it. The front spring however must project in front of the axle to secure the trailing, or so-called "castor" effect, essential to ease in steering.

The article as a whole opens up an important field by paving the way for experimental investigation of the problem. It would make for progress in this direction if the Society of Automobile Engineers should authorize a competent engineer to conduct a series of tests based on a rational analysis of spring suspension, and submit the results in a form available for manufacturing purposes. The expense of such an investigation would be negligible when divided up among the members of the Society, while the results would eliminate costly guess work, and undoubtedly standardize the design of springs.

HERBERT CHASE:—The following discussion,* was recently contributed to a French automobile paper, by Henri J. Burtart, and is of direct interest in connection with Mr. Akimoff's paper:

La Pratique Automobile, Dec. 15, 1916, p. 5104.

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The question of the suspension has become the most important among the incessant improvements that contribute to comfort. While a number of manufacturers have seriously studied the springs that should be employed, many have not even glanced at this problem, which has become really important.

At the moment when passing over an obstacle a person seated in a vehicle feels the increase or decrease of the pressure between his body and the cushions. That which is disagreeable is the instant during which this change of pressure is produced, and not the magnitude of the change of pressure itself. One could in effect be lifted perceptibly, that is, feel a great increase of pressure between the body and the seat without the sensation becoming disagreeable, while a smaller increase in the pressure, which lifted the body very much less, would give the sensation of a shock. This is due to the fact that in the first case the change in pressure was relatively less rapid than in the latter case. The springs will therefore be so much the better the more they prolong the duration of the change of pressure between the seat and its occupant.

When a wheel of the vehicle passes over an obstruction, the axle is lifted first and the rapidity of its upward motion depends on the speed of the vehicle; the chassis will only be lifted an instant later, and to a smaller degree, and as much less quickly the better the spring.

If one studies this problem by separating the actions that are produced, one can prove first of all that the axle is lifted at a greater speed than the chassis, while the upward pressure of the spring and the retarding effort presented by the friction of the leaves with each other have a tendency to add to the lifting of the chassis. An interval thereafter the chassis and the axle are lifted at the same speed; at precisely this instant, just as if there were no springs, there is no relative displacement produced of the chassis with respect to the axle. After that the chassis is lifted more quickly than the axle, but immediately, the retarding effort due to the friction of the leaves on each other changes this tendency and tends then to retard the chassis, that is, to counteract the lifting of the latter. It results from the examination of these three phases, that to avoid a too brisk variation in the speed of the ascending movement of the chassis, one must diminish as much as possible the friction that causes this variation.

With some types of shock absorbers which progressively increase the value of the friction, the object sought would be attained for the small deflections, as the value of the friction will remain a minimum; but in the case of considerable deflections, as the value of the friction is more considerable than when using a spring alone, the jolts will be rather increased.

It is necessary to grease carefully the leaves of the springs to avoid excessive friction. It is also necessary to adopt flat springs, as this is the best form for a diminished friction during the deformations.

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A friction shock absorber does not present any other advantage than to permit the use of a weaker spring; in other words, the result obtained is bad if one uses a friction shock absorber without changing the springs supplied by the manufacturer.

The liquid shock absorbers would not present the same difficulties as the friction shock absorbers, but unhappily the viscosity of the glycerine varies considerably with the temperature. Naturally this rises very materially in the shock absorber when the vehicle is traveling over a bad road. With oil, in cold weather, one risks breaking the whole device when starting, if the oil is solidified.

There are also in existence shock absorbers that are placed at the end of the leaves. They increase the amplitude of the oscillations, acting in the same manner as if the springs had been made weaker; they can therefore only present a real advantage in the case where the springs provided by the manufacturer are too stiff. These last mentioned shock absorbers do not introduce any friction, but, on the contrary, they have a tendency to diminish the value of the friction proper of the spring itself.

It may be more advantageous to adopt these last mentioned absorbers in combination with springs somewhat stiff, instead of retaining rather weak springs, because, as we have seen, the value of the friction on the whole structure can be reduced. Besides, the shock absorbers so placed diminish the shocks due to the friction proper of the spring.

In practice it has been observed that the frequency of the oscillations of a spring should be between 76 and 100 per min. The smaller this number the better the suspension. The manner of measuring the frequency is very simple; step on the running-board of an empty car, balancing it up and down and taking care to accompany the movements of the oscillations so obtained with the body. Count the number of oscillations per minute that can be obtained.

In principle, if one can accompany the oscillating movements, the suspension is good, for it is impossible to follow the flexions beyond 100 per minute. If the suspension is too stiff, the feeling will be evident at once that the muscular movements cannot accompany those of the springs.

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AERIAL NAVIGATION OVER WATER

By Elmer A. Sperry
(Member of the Society)

Abstract

The author calls attention to the unreliability of the magnetic compass when used for aerial navigation and to the possible development of the gyroscopic compass for this purpose. He then explains how the drift of an airplane in flight makes it difficult to follow with accuracy a given course devoid of landmarks, unless an accurate drift indicator using the principle of the stroboscope is available.

The development of such an instrument is then described, as are also means for synchronizing it with the compass. The use of the automatic synchronized instrument in flight over land is outlined, and its application to flight over water is described in considerable detail. Rules for aerial navigation over water, observation as to movement of wave crest and determination of wind velocity and direction are considered in their relation to the use of the instrument.

The author, because of the development and practical application of his gyro-compass, has been brought to consider, more or less broadly, the whole science of navigation. For many decades past, this science has been one of high exactitude, limited only by the accuracy of the instruments used in obtaining its ground work or in giving it its base lines.

It has long been known that the magnetic compass is unreliable; as ships represent greater and greater masses of steel, this inaccuracy has become more and more aggravated. Methods of checking its accuracy have been diligently sought for and made as nearly perfect as possible. These, however, depend upon observations and fail usually just at the time they are most needed; namely, when observations of the heavenly bodies are impossible. All this emphasizes strongly the desirability of an instrument of precision that will function as a compass. The adaptation of the gyroscope is found to fulfill this satisfactorily.

LIMITATIONS OF MAGNETIC COMPASS

Among the difficulties met in using the magnetic compass in the air is that known as the heeling error. When a magnetic compass is used on airplanes, and the machine is even mildly "banked," and persists in such a position for an appreciable period, the heeling error is found to be of such magnitude as to render the compass useless. In some instances it will amount to 360 deg., or around the entire circle, giving no clue whatever to the aviator as to the true azimuth, or where to stop on the turn and straighten out into the tangent. Thus the compass fails him utterly at just the critical

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time when it is most needed. After the tangent is persisted in for a sufficiently long time for the compass to settle, then and then only does it again become useful.

Moreover, the lag or tardiness of action of the magnetic compass is a serious drawback. The magnetic compass, to be reliable, we find, must be of the so-called liquid type; upon spiralling and making two or three turns the liquid is found to take up the swivelling motion, carrying the card with it round and round, and becoming a serious disturbing factor for some time after the airplane straightens out on the tangent. This is not meant to imply that the magnetic compass is not an extremely useful instrument upon aircraft, but for best results it should be understood by the aviator and not relied upon when conditions are such that it is impossible for it to function.

This condition has become so aggravating that the United States Navy is ordering a gyroscopic compass to be employed on airplanes. By extreme refinement in execution and design it is expected by the Navy Department that the weight of this instrument will be reduced to 20 or 30 lb.

When one is navigating the air and holding an absolutely true course, that is, with the lubber line of the compass precisely upon the desired heading in azimuth, the direction of flight coincides with this heading, under the condition of absence of movement of the medium, namely the atmosphere, through which the flight takes place. At first thought, one would think that at the moment the medium itself was moving, and especially when this movement was normal or at a small angle to the direction of flight, the compass would instantly indicate the resulting deviation from the true course. This conception, however, is not correct.

An aviator can hold his course true to the compass and still be following a course having a wide angle of deviation from the course in which he thinks he is flying. For instance, Carlstrom, in his noteworthy flight from Chicago to New York (equipped with instruments described later), found he was drifting 17½ deg., when flying over Cleveland; his apparent course had to be changed to this extent to neutralize drift and to maintain the true direction along the south shore of Lake Erie. This angle was given him by his drift set, which, although not indispensable, he used throughout his flight. Carlstrom, however, had the shore line and general land marks to aid in his guidance. The case would have been different had he been flying at sea out of sight of land, where no land marks could possibly be seen. Then certain aids to navigation are indispensable, and it is the province of this paper to discuss briefly some general aspects of these instruments and their uses, no effort being made to present a mathematical or an exhaustive treatise on the subject.

DETERMINATION OF DRIFT

Let us assume an airplane maintaining a compass course due

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north with the lubber line of the compass maintained at zero on the card, and for the moment the compass properly functions without variation or deviation. In still air the course of this machine over the surface of the earth will be north. But suppose, wholly without

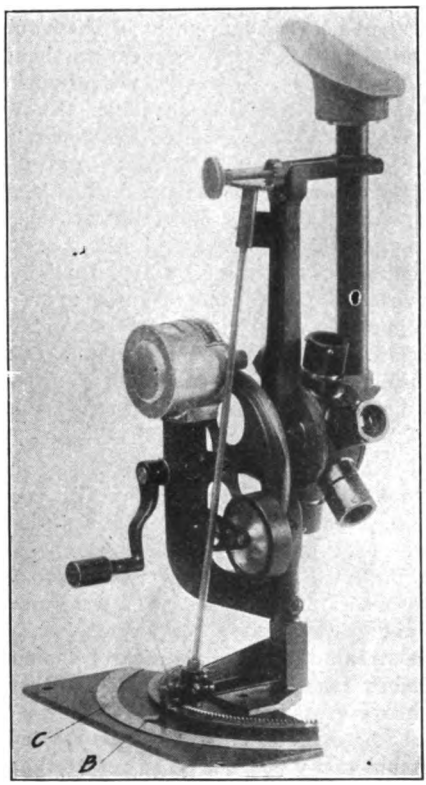

FIG. 1—EARLY FORM OF DRIFT INDICATOR

the knowledge of the aviator, the medium in which he is flying is itself in motion toward the east with a velocity equal to that of the aircraft. It is quite evident that, although he holds his course with exactitude, the craft itself is passing over the surface of the earth on a diagonal, that is, his actual course is northeast; the easterly component of his course depends upon the eastward velocity of the medium. Again, if this velocity be half of that of the aircraft, then his real course is 22½ deg., or "north-northeast." The question arises: how is the pilot to obtain this knowledge, or knowledge

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that he is drifting at all, so as to make the necessary correction of course in the absence of landmarks or other indications to guide him?

A device, worked out by the author some time ago to give pilots this knowledge, has now come into general use, and is found to perform its function satisfactorily. Fig. 1 shows an earlier form of this device, in which a series of moving observing tubes acted as a stroboscope. By the backward movement of these tubes a point upon the earth's surface could be made to appear as though it stood still; the backwardly moving point of persistence of vision being exactly equal to the forward advance of the machine. Knowing the angular velocity of these vision tubes, or simple telescopes, and the altitude, the actual speed over the earth's surface was at once obtained. When compared with the anemometer speed, that is, the real speed of flight through the atmosphere, a clew was at once available as to the actual movements of the atmosphere itself.

This instrument was then carried a step further. The telescopes were furnished with cross-hairs and mounted upon a swiveling base with a pointer *B* moving over an azimuth scale *C*. When the slow motion of the telescopes was arrested and one telescope furnished with one or more fore-and-aft cross-hairs pointed directly downward, it was found easy to make a peculiar reading known as the "stream-line observation."

When one is looking downward at the surface of the earth, through a tube or telescope, if, instead of looking for specific objects, he simply observes the passage of *all* objects across the field of the tube or telescope, he at once becomes conscious of the passage of all of these objects taking place in certain clearly-defined parallel lines, which I have termed "stream-lines." When one gets somewhat familiar with this kind of observation, he can see almost nothing but these stream-lines, and the nearer the surface or greater the speed, the more tense and clearly-defined these lines become. Now, if a good, heavy cross-hair be stretched across the tube or telescope, and the tube be made so that it can be rotated upon its major axis, then it is found easily possible so to rotate the tube as to bring the cross-hair exactly coincident or parallel with the stream-lines.

The rotating tube or telescope is furnished with a stationary scale, the zero of which is coincident with the longitudinal axis of the aircraft. By taking readings on this scale with a pointer on the tube opposite the cross-hair, it becomes easy to determine the angle between the stream-lines and the major axis of the aircraft, since the latter always lies in the apparent direction of flight, the angle being between the stream-lines, or actual direction of flight, and the aircraft. The determination of such an angle as this is extremely useful, as it at once gives the aviator a clew as to what change to make in his course so that his direction of flight is such as to neutralize the drift of the medium through which he is flying, his actual course being thus brought into exact harmony with the direction required to reach his destination.

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In securing this parallelism the pointer *B* is swung upon the scale *C* and the angle of drift in degrees can be immediately read on the scale from the longitudinal axis of the aircraft. Many surprises are in store for the pilot or observer when he first makes this observation, as he often is certain that it cannot be correct. He cannot believe it possible from his compass heading, to which he is hold-

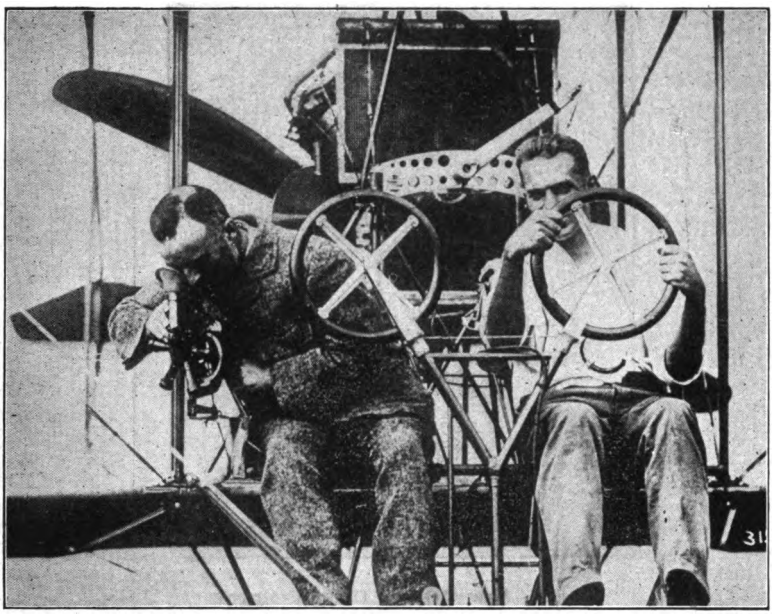

FIG. 2—DRIFT INDICATOR IN USE BY NAVIGATOR

ing with great accuracy, that he is actually making headway at so large an angle from its readings. And if he has had experience at sea with the compass, this impression is all the more startling, because it is always true that a ship is traveling practically on the exact course indicated by its compass. But here the pilot is holding his course absolutely true to the compass, and yet the drift indicator shows a quite different condition of affairs; namely, that he is actually traveling at a considerable angle to his supposed course.

Fig. 2 shows the instrument described mounted upon an airplane and being used by the observer. The observer in this instance is Captain Creagh-Osborne, R. N., head of the Hydrographic Office of the British Admiralty. The pilot is Lieutenant Towers, U. S. N.

With the earlier instruments the pilot would change his course and by trial in error finally reach a flight heading on the compass card, resulting in actual headway of the aircraft along the true

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course; that is, along the line that he was originally instructed to pursue to reach the desired destination.

Thus it will be seen that the accurate determination of drift is an important factor in aerial navigation. It is true that observations are somewhat more difficult at great heights and over rough water,

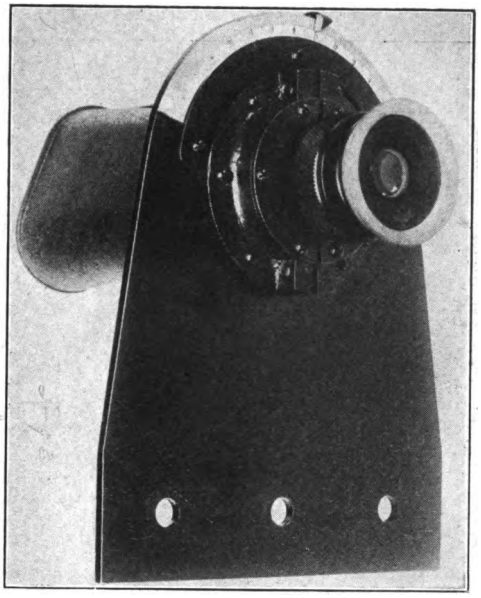

FIG. 3—NEW TYPE OF DRIFT INDICATOR

but one soon becomes accustomed to obtaining a mean reading, which is found to be very accurate. It has also been definitely ascertained that when flying with the automatic pilot, with which side disturbances are practically eliminated, the stream-line observation becomes very much simplified and accurate at practically all altitudes.

THE SYNCHRONIZED DRIFT SET

A later form of the apparatus is shown in Fig. 3, in which a single stationary telescope, provided with the cross-hairs, is employed for the moving series of telescopes, inasmuch as the drift factor is found to be of far more importance than the actual speed of advance with reference to the earth's surface.

In Fig. 4 is shown a drift compass with an adjustable lubber line and with a little tiller wheel extending from the side of the case, by means of which the lubber line is set from the indications upon the scale *C* of the drift indicator. The scale upon the bezel of the compass is used for reading the deflection of the lubber line. Care must

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be taken in moving the lubber line to be sure that its setting is correct as to direction, and that it is not set on the right side of the zero when it should be on the left.

A pilot, especially when without the automatic pilot and working alone, has enough cares without the added one of worrying whether the compass has been accurately synchronized with the

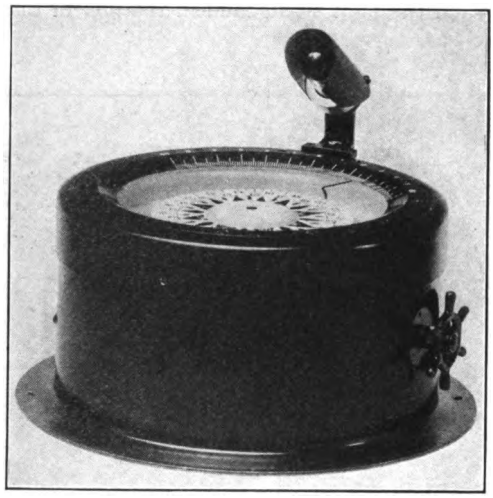

FIG. 4—DRIFT COMPASS WITH ADJUSTABLE LUBBER LINE

drift indicator, and whether the direction of the adjustment is also correct. So the idea was conceived of coupling them mechanically, in order that they might be at all times automatically synchronized. The combined instrument, namely, the synchronized drift-set has now become the most useful form of the apparatus and the one most widely adopted. In this instrument the most minute azimuth movement introduced by the observer at once causes a corresponding alteration of the position of the lubber line of the compass, thus eliminating the possibility of error either in the direction of this movement or in its exact amount. This is found very practical, inasmuch as it vastly simplifies the pilot's operation, he needing only to continue without change to hold the lubber line upon the originally selected point on the compass card. The fact that the lubber line is displaced, especially if under the control of the observer, is something with which the pilot has nothing to do and is not concerned—he simply continues on his original compass course. This arrangement automatically introduces all of the deviations in course to correct fully for drift, and is found to save much valuable time and fuel, and to allow the pilot to reach his destination by a true meridional course. With the actual drift known and corrected for, the correction that should be given the

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anemometer speed, which is always known to the operator, can be determined easily. Thus he has all the knowledge of the actual forward advance that is roughly necessary in short flights.

Fig. 5 shows the synchronized drift set with the observing telescope to the left, the compass to the right, and the compass lubber line thrown around 30 deg. from the longitudinal axis of the aircraft indicated by the zero on the scale shown on the bezel. When the observer and the pilot sit in tandem relation in the aircraft, then

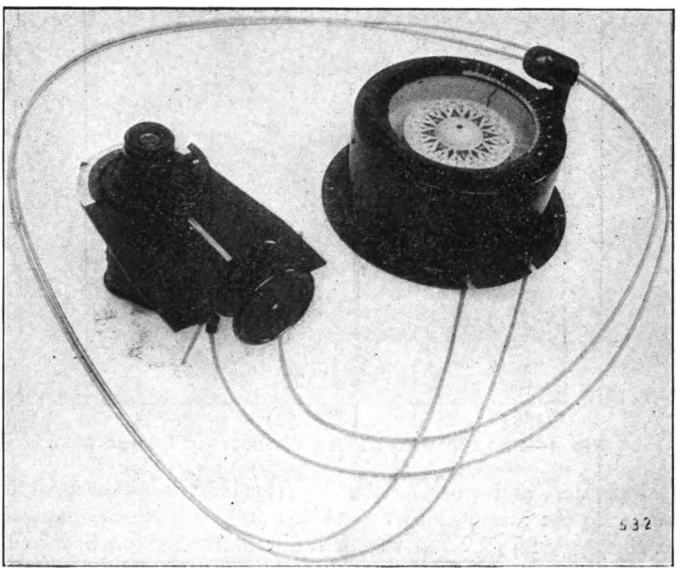

FIG. 5—SYNCHRONIZED DRIFT SET (OBSERVING TELESCOPE AT LEFT)

it becomes desirable that each have a compass. Fig. 6 shows a set in which two compasses are synchronized by means of a single drift indicator.

It is always wise to note the direction of the wind before starting, and also something as to the length of the wave, that is, the distance from wave crest to wave crest.

In leaving the surface of the water, it should also be the duty of the personnel to see that the aneroid is adjusted exactly on zero. This observation should also be made whenever the plane is brought close to the surface, thus eliminating effects of changes in barometer in determining actual heights. The uses of these observations will be presently apparent. Let us now divide the problem of speed control into two classes.

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In the first class stroboscope methods are used. One form of the stroboscope is shown above in Fig. 1. Another instrument working upon this principle is illustrated in Fig. 7. Still another simpler form is in course of being developed for the U. S. service. The speed with reference to the surface of the earth can be ascertained with a good degree of accuracy over water. It is, of course, necessary to know the movement of the sea, or, rather, its apparent movement, as for instance, the movement of the wave crest.

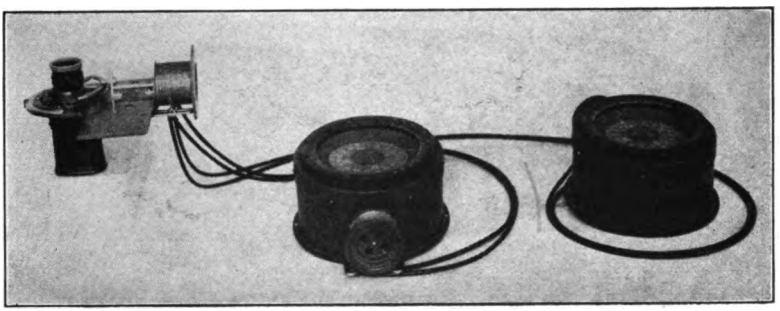

FIG. 6—SYNCHRONIZED DRIFT SET WITH TWO COMPASSES

In every instance the actual angular velocity of the stroboscope, or of the apparent passage of the earth's surface, and the careful reading of the aneroid are used as prime factors.

The second class is where a close approximation of the actual speed can be ascertained quickly. Using the anemometer speed as a base, we determine whether the actual speed is the same as, or greater or less than the anemometer speed, and also obtain a close approximation of how much the variation is. It is assumed that the anemometer speed is always available to the navigator. A good anemometer is known to possess a high degree of accuracy.

When the wave crests are small and cannot be seen directly, the same telescope that is used to ascertain the stream-line directions can be employed to observe the direction of the wave crest. Fig. 8 is a reproduction of a photograph taken from a considerable altitude, and shows how clearly visible these wave crests are. They are an indicator of two valuable factors: First, from their length from crest to crest we can ascertain their speed; and second, their direction always lies directly normal to that of the wind. The waves shown in Fig. 8 are about 10 ft. from crest to crest, giving us a velocity of 7.2 ft. per sec. It might be difficult to know in which direction these waves are moving, but with the conditions such as in Fig. 8, there is the simplest possible clew consisting of the vapors flowing from the funnels of the two small craft shown. The line of these vapors is to be normal to the line of the wave crests.

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Bearing these points in mind, the following rules can be applied to aerial navigation:

1. Note on which side of the keel line or longitudinal axis of the aircraft lies the actual or true course, or on which side of the zero on the bezel of the drift compass lies the adjustable lubber line. This is the "drift side," and can, of course, be to the right or to the left. (The zero on the bezel indicates the keel line.)

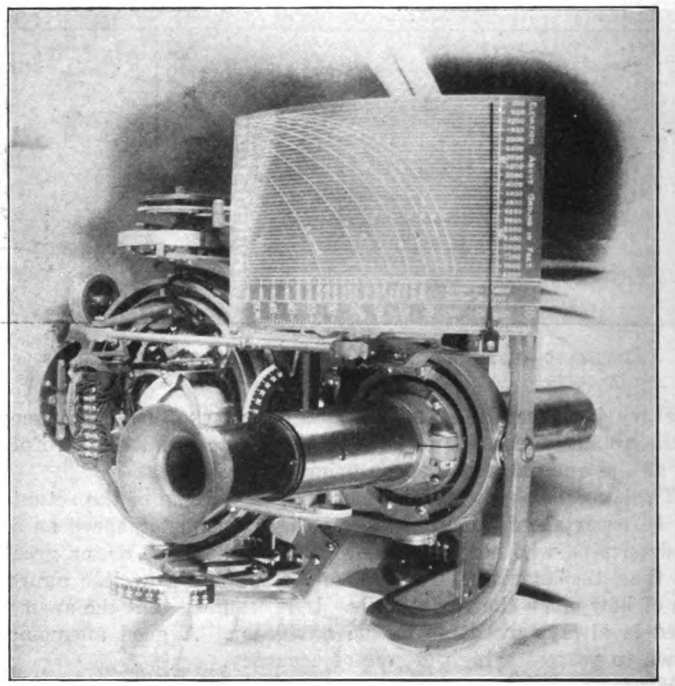

FIG. 7—SPEED INDICATOR USING STROBOSCOPE METHOD

2. Note closely the apparent alignment of the wave crests while the aircraft is being maintained on its course.

3. Note the relative angle between the wave crests and the keel line, and also between the wave crests and the "drift line," or the alignment of the adjustable lubber line.

With these observations well in hand, the following deductions can be made:

a. If the crests lie within the angle between the keel line and the drift line, then the real speed is approximately identical with the anemometer speed. If these crests exactly bisect this angle, then

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the real speed on the actual course is exactly the anemometer speed.

b. If the aft ends of the crests be toward the drift side, then the actual speed over the earth's surface is always greater than the anemometer speed, because of an abaft wind.

c. If the aft ends of the crests are away from the drift side to a greater extent than is the true course angle or drift line, then the actual speed is always smaller or less than the anemometer speed, because of head wind.

d. If the crests lie exactly at right angles to the keel line, of

FIG. 8—WAVE CRESTS VIEWED FROM AIRPLANE

course no drift angle exists, and the stream-lines lie parallel to the keel. However, it is always known which way the wind is blowing, from observations made before starting (which have been referred to), and in this manner we at once know whether we are passing over the surface of the earth at a faster or a slower speed than that indicated by the anemometer. Suppose, however, the navigator should

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have mislaid his data or forgotten the direction of the wind or its true azimuth. A clew to the direction can be obtained as follows: Change the course sufficiently to make the stream-lines veer away from the keel line. If the leading ends of the stream-lines are seen to move to the left for a right turn, the wind is a *following* wind, and if they move to the right for a right turn it is a *head* wind. Of course, for a left turn just the reverse is true. As to whether the velocity is great or little can easily be judged from the sea conditions.

In Figs. 9 and 10, *b* is the forward part of a flying boat in outline; *k* is the keel line; *l* is the lubber line; *c* is the compass card. The zero on the compass bezel is on the keel line; *sl* indicates the stream lines and their direction; *p* is the point on the compass card indicating the desired direction of flight. In Fig. 10 *l* and *l'* indicate the "drift line," or true course.

MOVEMENTS OF THE WAVE CRESTS

As a still further refinement in ascertaining speed and direction, account should be taken of the movement of the wave crests themselves. This can ordinarily be found by determining the length between the crests, inasmuch as the velocity varies about as the square root of the wave length or distance between crests; the velocity in feet per second equals the wave length in feet at a point where each is expressed by the figure 5⅛—to be accurate, 5.123—that is, when these measure the distance from crest to crest, their velocity is also 5.123 ft. per sec. The 10-ft. wave shown in Fig. 8 would therefore have a velocity of about 7.2 ft. per sec.

We know the approximate length of this wave, having observed it before leaving the water; but if this has not been done, we can ascertain the length by dropping down near enough to the surface of the water to get a fairly accurate determination of the mean lengths between wave crests, taking this opportunity also to note that the aneroid is at zero. Having thus determined the velocity of the wave crests, we proceed to determine the necessary corrections.

Corrections for Movement

With reference to the speed, a correction should be made in proportion to the sine of the angle between the wave crest and the stream-line. To obtain the actual speed over the earth's surface, we should add the speed of the wave crests to the speeds obtained by stroboscopic methods in all cases of following wind, and subtract in case of head wind. The amounts that are subtracted are equal to the velocity of the wave crests only when the wave crests are at right angles to the stream-lines. At other angles the velocities subtracted or added are as the sine of the angle between the wave crests and the stream-line.

In order to find the influence of the moving wave crests on the apparent direction of the stream-lines, the angle between the stream-lines and the wave crests should be determined; and starting with the

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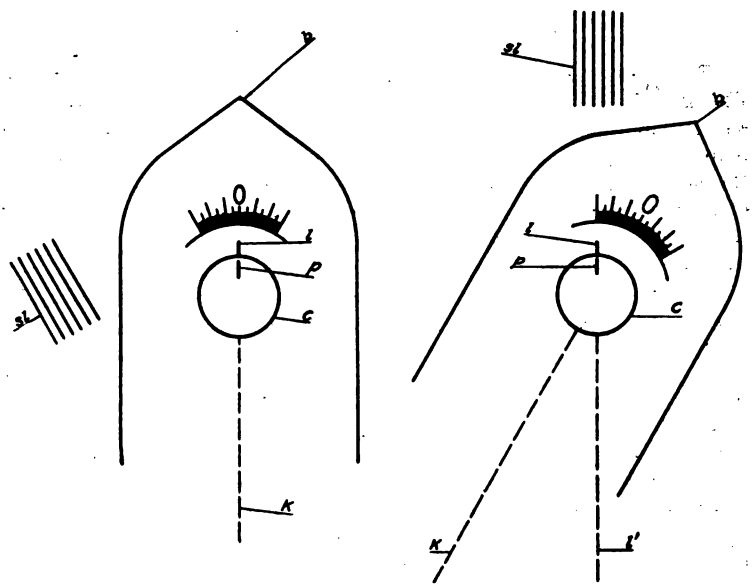
position where the stream-lines and wave crests lie parallel to each other, as being the condition of maximum correction, we derive this correction from the known velocity of the wave crests. The correction, it should be remembered, is an angular correction to be applied to the apparent direction of the stream-line, resulting in a refinement of heading which gives the true meridional course to the point of destination.



FIGS. 9 AND 10—OUTLINE OF FRONT PART OF FLYING BOAT

This correction is always proportional to the ratio of the velocities of wave crests and aircraft determined, say by stroboscopic methods or by the anemometer, after the proper corrections have been applied. When the wave crests and stream-lines are parallel, this ratio is applied directly. When other angles obtain, the correction should be multiplied by the cosine of the angle between the wave crests and the stream-lines.

One factor now remains, that is, as to whether the correction is to be applied clockwise or anti-clockwise. Assuming the observer is facing the direction of the stream-line or actual flight, then if the wind is from the right the correction should be counter-clockwise, and if from his left the correction should be clockwise.

There are a number of other interesting aids to navigation of aircraft, such as clinometers, gyroscopic base lines, and artificial horizons, banking indicators, angle of incidence indicators, and the like, but their uses are apparent and need little explanation.

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PAPERS PRESENTED AT AERONAUTIC SESSION OF THE SOCIETY

STANDARDIZATION OF METAL PARTS FOR AERONAUTIC USE

F. G. Diffin

(Associate Member of the Society)

The subject of standardization of airplane parts is a broad one. The growth of the aeronautic industry has been exceedingly rapid and in the immediate future will be tremendous. It is my confident belief that its size and importance will rank closely with those of the automobile. It is therefore of paramount importance that immediate and intelligent action be taken by recognized authorities toward the definite standardization of parts. As my aeronautic experience has been entirely in the manufacture of metal parts and fittings, I am confining my remarks to existing conditions and to recommendations toward their permanent betterment.

First, let me enumerate the bulk of troubles now met by parts manufacturers and passed along manyfold to airplane manufacturers. Of screw-machine products alone, on a well-known type of machine, there are over 3,000 separate parts. Many of these call for from two or three to as many as ten operations looking to their completion. While the majority of manufacturers run somewhat along the same line in their specifications, we have to-day orders for one specific size of bolt, for practically the same use on various makes of machines, calling for the use of six different metals. We are asked also to make this bolt in over sixty different lengths; practically the same condition exists in eight different diameters. It will thus be seen that should such specifications become general it would be necessary on hex head bolts alone for us to manufacture 2,880 separate items in order to fill airplane requirements. It is my belief that fully 75 per cent of these specifications can be eliminated.

An additional bolt complication is the varying thickness of head called for by the different manufacturers. There can be only one head that is necessary, that is, the head with the necessary thickness to give a proper factor of safety. Any additional thickness is superfluous and adds materially to wind resistance and weight; while a thinner head is dangerous.

VARIETY OF PARTS

We are asked to furnish several hundred different rod and yoke-end pins—in fact, nearly a thousand separate items involving various diameters, lengths, different size of cotter-pin hole, different radii on the nose and different radii and thicknesses on the heads.

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We are asked to make many different thicknesses of castle nuts, nearly all being for the same purpose. Some call for cold-rolled steel with and without case-hardening and others for nickel steel. Some of these specifications can be eliminated. Machining of nickel-steel castle nuts is one of the most difficult operations we have had to contend with; we are frank to state that we are by no means satisfied with the results obtained so far; and we are not fully confident that entirely satisfactory results can be obtained. The difficulty pertains to the cutting of a true thread.

We are asked to manufacture various other parts, such as eye-bolts, shackles, terminals, of various sizes; and other parts too numerous to mention; all to a wide range of specifications. It is obvious of course, to all men expert in aeronautics that the ultimate uses are the same; it is of vast importance that the various dimensions and varied sizes of these parts be minimized as far as possible and, let me urge, as quickly as possible.

I have enumerated troubles in general from the standpoint of the manufacturer of parts. I will now tell what these mean to the airplane and engine manufacturer. With the wide divergence in size, and many kinds of material called for, there are many very small orders for each part, each being urgently needed. In order to secure production for automatic machines, it is absolutely essential that fairly long runs be put on each machine. We have frequently changed our tools on a machine several times a day in order to produce the small number of parts required. The buyer is frequently at a loss to understand why his order for 100 or 1,000 bolts, as the case may be, is so long being filled. Could this wide range of parts be cut down materially the parts manufacturer would be further warranted in running stock, provided he had any assurance that the size would be in demand in the future. To-day we are uncertain as to what will be required in that future. Such a standardization would be of great benefit to the parts manufacturer and of much greater benefit to the airplane manufacturer.

At a small gathering of airplane men a few months ago I was optimistic enough to make the prediction outlined in my opening remarks, but qualified the statement by saying that the number of airplanes manufactured would depend on the productive capacity of parts manufacturers. The situation in this regard has become very acute to-day, but will become more so in the near future. To the average man it seems a simple matter for any parts manufacturer to furnish the airplane manufacturer's requirements. We have proved to our own satisfaction that the machining of airplane parts is a business by itself, to be taken up in a small way, as then machines can be adjusted to speeds, feeds, etc., for nickel-steel production, and men can be educated in the production of parts to the absolute specifications required. All this takes time. While the company I represent is not a large factor in the manufacture of airplane parts,

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it has taken us over one year to build up a good manufacturing organization, and even if we could obtain the equipment, we would not feel able to double our production, except as we could gradually increase our organization, keeping it in all branches up to necessary efficiency.

The metal fittings now being required in airplanes are in the same class as screw-machine products, as many and various types are required. Could these become standardized, the airplane manufacturer would find that the cost of many of these parts would be but a small fraction of the present cost.

Probably the most important individual factor in airplane manufacture is the turnbuckle. As such it should be treated by itself in a separate paper, since this paper is intended to treat more particularly of such items as bolts, nuts, and rod and yoke-end pins. I will confine further standardization recommendations to these items.

ADVANTAGES OF STANDARDIZATION

While many of my criticisms of existing conditions and recommendations for their correction are almost too obvious to require mention. I will nevertheless speak of the more important ones, state in what way standardization will benefit all parts of the industry, and recommend the line of least resistance to follow.

1—The more important results to be gained from standardization are greater and constant production from parts makers, the result of which is the possible manufacture of a greater number of airplanes. This is of particular interest to the Government, against an immediate need for the manufacture of large quantities of machines.

2—The airplane manufacturers will be able to effect large savings in their costs and general operation. They will be required to carry less stock, as the number of parts will be much less, and they will be sure of certain supplies in the quantities needed, and a greatly reduced price per item.

3—The manufacturers will find that in assembling, uniform parts will be of great assistance to them.

4—The future owners, either Government or individual, of airplanes, will be able to obtain readily necessary repair parts.

5—Of particular interest to the Government, which will purchase various types of machines in the near future, is the fact that standardization of parts will mean interchangeability of parts for the various machines it will use. This will be an important advantage in operating supply depots.

6—One of the greatest reasons for standardization is this: Unless rigid standards are specified and strictly adhered to by both parts and airplane manufacturers a large element of danger will be introduced. The rush of work incident to manufacturing parts to many different specifications will result in improper use of metals,

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incorrect heat treatments, etc. The inevitable outcome will be serious accidents in flights, resulting in loss of life and lack of confidence of the public in the stability of airplanes.

The big future of the airplane, which we all anticipate, can be secured only by creating in the public mind as much confidence in the safety of flight as now exists in the safety of the automobile.

SPECIFIC RECOMMENDATIONS FOR STANDARDIZATION

The selection of the particular type of alloy steel is directly controlled by the function for which the member is designed. There would be no direct advantage in using an alloy steel for such parts as washers, sheet metal parts and, in my judgment, nuts.

Designers' specifications must necessarily contemplate both the theoretical considerations and the practical methods of manufacturing. Consideration must be given to the material-producer's point of view in order to avoid an unnecessarily severe specification to accomplish some relatively minor purpose. While, at all times, a high grade of material, far above the average commercial type, is demanded, full regard should be paid to the methods of economical production.

Bolt Dimensions and Materials

Referring now to the subject of bolts, I recommend:

1—That lengths be standardized as far as possible.

2—That needless diameters be eliminated; for instance, there is no practical need of both 3/16 in. and No. 10 bolts.

3—That material for bolts to be used for certain purposes be clearly specified. One material only is necessary for a given purpose. In the majority of instances to-day 3½ per cent nickel steel with proper heat treatment fills the requirements, with liberal factor of safety.

4—A certain standard should be fixed for thickness of head. Up to certain diameters, let there be one fixed thickness; above this diameter each head should be a certain fraction of the diameter; all to be determined for necessary strength plus a factor of safety. Of this specific item, the parts manufacturer is asked to make upward of 15,000 separate items. By standardization a large percentage of these items can be eliminated.

Rod and Yoke-End Pins

Referring to rod and yoke-end pins, my recommendation is: limit the number of diameters and lengths to the fewest possible. When a cotter-pin hole is required, let this be the same size in all pins of given diameters.

As the head of the rod and yoke-end pin need be no stronger than the cotter-pin, it is necessary that this be of only one definite thickness proportional to its diameter. Different radii on the edges are absolutely useless.

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Nut Requirements

We have thoroughly investigated castle nuts, both in our own laboratory and through the testing departments of other manufacturers. We believe, for economical production, accurate production and quantity production, that the use of nickel-steel nuts is no longer necessary. The function of a nut is to bear perfectly upon the threads of the alloy-steel bolts. Satisfactory results can be obtained by using cold-rolled steel of proper carbon content and properly case-hardened.

For a certain diameter of bolts the desired results can be obtained by the use of one thickness of nut only, and the innumerable specifications used to-day by various manufacturers, as to thickness, radius, etc., should be reduced to the one practical dimension and radius required.

A source of ever-present manufacturing difficulties is in ball-head nuts and bolts, due to the varying radii required. The size of this ball head and nut is necessarily controlled by the function of the member in which they are placed. As at present designed, they have several hundred per cent excess strength.

As the different designs of head and nut, both as to radius and thickness, are many and varied, one radius, one thickness and one diameter in proper proportion to the metal and diameter of the shank are all that is necessary.

AUTHOR'S CONCLUSION

These few recommendations are of great importance. If standardization of these parts be immediately undertaken, great benefits will be derived.

As these parts are standardized many others will require the same effort. We all concede the need of standardization and the great results to be obtained from it.

I cannot emphasize too strongly the urgent necessity for the immediate standardization of all airplane parts.

DISCUSSION

F. G. DIFFIN:—On the hex bolt we have alone in our factory today orders for four separate thicknesses of head. As I have stated in my paper, certainly only one thickness of head is necessary on the same diameter of bolt. The specifications for bolt threads are almost without number. We have, of course, machines for threading the bolt, and I do not believe we get 25 per cent of the possible production on those machines because of the number of changes we have to make on account of the varying specifications.

We have found in every instance in testing a bolt for tensile

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strength that the bolt always breaks in the first thread. A thread or two more or less will not make any difference or change in the strength of that bolt unless there is a direct 45-deg. pull on that particular spot.

We have seen three different specifications for rod-end pins, calling for different-size cotter holes. We have had three separate radii on the nose of the rod-end pin.

I do not want to make these suggestions too commercial. It is a saving in dollars and cents to us, because the minute we can get greater production the price will logically and naturally decrease. At the start we took a large volume of business and our books showed a heavy loss. We cancelled that business, started in more slowly, and we have reached a point where we are getting a fair production. During December our machines were running 30 per cent below the normal amount of production. A good deal of that was due to the innumerable times we had to change set-ups on the machines. If the parts are standardized and we are reasonably certain as to the number of a certain nut that will be used in the course of a year, we can have machines set up and run them all the time. When the orders come in for 500 in a hurry, we can send them right out.

If standardization is effected in these minor items and the same principle applied all the way through, it unquestionably will work out a great deal more to the advantage of the airplane manufacturer than to that of the parts manufacturer.

A. LUDLOW CLAYDEN:—Possibly the greatest difficulty will be to obtain agreement upon material. Many engineers will not be prepared to accept nuts of softer material than that used for the bolts. In all aviation standards the importance of weight must never be lost sight of for an instant. Supposing there were a hundred nuts on an engine and that by using alloy steel instead of ordinary carbon stock we could save 1/10 oz. on each nut? This would cut the weight of the engine over ½ lb. This in itself might be of no importance, but if you took every nut on a plane and added some fraction of an ounce to it, it would probably be surprising what a total of weight would have been added. It is just by being extremely careful in matters of this sort that weight has been cut down.

Aircraft standards differ from automobile standards, and in one other important respect: their object is at present to facilitate supply rather than to decrease cost. Of course, the two things must go hand in hand, but the design of aircraft has not yet reached the stage where it is possible to sacrifice anything for the sake of manufacturing facility. It is the desire to turn out machines quickly and still more perhaps the desire to obtain replacement rapidly that will enable the new industry and the new standards to grow up together.

In one way, however, the task of standardizing aircraft parts should be very much easier than that which presented itself with respect to the automobile fittings that the S. A. E. first created. With automobile standards it has been necessary to explain continually in

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what way they benefit the manufacturer and user. In the case of aircraft the demand for standards originates with the user, and I believe every member of the industry is fully alive to the immense assistance that good standards will be in the development of the use of aircraft of all kinds.

FUNCTION OF STANDARDIZATION

N. W. AKIMOFF:—The standardization work done so far is limited to the shop end of the problem; some practical man suggests the adoption of a certain thread, or of a certain thickness of bracket for holding the battery, or a certain width of the oil groove. Then other practical men argue the thing out and finally adopt the proposed standard in its original or modified form.

But the events of the past few days may result in confronting us with a problem in which we must show that we excel the other fellow not only in uniformity of petcocks or castle nuts but in other things as well. While we are about it, why not standardize the design of the engine as much as possible, that is, the purely engineering part of the proposition? In this way the production man would work at one end of the problem and the engineer at the other, and the results would be manifest right from the start.

The piston, for example, can be standardized. All its characteristics, including the weight, can be given in function of one variable only, its diameter, ranging, say, in quarters of an inch up to a certain maximum.

The connecting-rod can be standardized. It is more than likely that the present anarchy as regards the lengths and weights can be boiled down to a well-worked-out table including the weights and the radii of gyration of each type, thus not only recommending but *insuring* the absolute uniformity of the product.

Last but not least comes the crankshaft. If we are to limit ourselves to the six, eight and twelve-cylinder types of engine why not standardize the few (probably only about six) types of shaft, recommending each type for a certain duty, in strict accordance with the conditions under which it is to work?

If the average engineer puts on counterweights, he mostly does it by rule of thumb, and immediately gets into trouble as regards torsional vibrations; also, to proportion a shaft without regard to the moment of inertia of the flywheel or propeller on its end is absurd; likewise, not to take into account the gyroscopic forces is another mistake; yet who checks up the proportions of projecting end according to St. Venant's simple formula, in conjunction with the well-known expression $I\Omega\omega$, giving the bending effort due to possible precession?

A special committee should be appointed for working out these finer points of engineering. Its object would not be to restrain anything, but to recommend certain proportions, precisely as is now being done in shipbuilding practice, where valuable rules are laid down by Lloyds and Veritas.

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BOLT MATERIAL AND DIMENSIONS

E. H. EHRMAN:—With Mr. Diffin, I wonder at the necessity of the many different dimensions for the same part of the same size of bolt, nut, rod and yoke-end pin. There are, I believe, enough well established standards covering these parts to obviate the necessity of specifying dimensions outside of their range.

I can see reasons for variety in specification of materials until our greater experience unifies good practice; this is quite different from that of proportions. The speaker mentions the difficulty of cutting good threads when nickel steel is used. It is possible that vanadium-alloy steel will serve the purpose as well as nickel steel, they machine much more satisfactorily than the latter. In the automobile industry several of our customers have followed our suggestions and are getting parts better machined as a consequence of their being made of a vanadium-alloy steel instead of nickel steel. Mr. Diffin also suggests the use of cold-rolled steel as being an adequate material from which to make nuts. I think his statement should be qualified to read cold-rolled open-hearth steel.

I believe the Miscellaneous Division of the Standards Committee will be glad to receive information relative to the deviations from standard, and to the diversity of proportions of bolts, nuts, rod-end pins and other parts, as it expects to consider bolt proportions during the coming year.

STANDARDIZATION ITEMS

WILLIAM F. THOMAS:—At present it should be possible, with comparatively little effort, to obtain the cooperation of airplane manufacturers for mutually beneficial purposes in arriving at standards not only for the parts mentioned in Mr. Diffin's paper but also for many other airplane parts.

Standard hub dimensions, methods of spoking and size of spokes might be adopted for airplane wheels, as might also steering wheels in 12, 15 and 18-in. diameters, with standard types of spiders and control operating drums. Engine bolts with large heads, designed for the purpose of giving large bearing area on wooden engine beds, and having a number of standard diameters and lengths, are suggested for standardization. Large tapered washers for use on wood might be standardized. Pulleys for control wires, airplane tank filler caps and a great many other similar details which at present are being made up in our shops would gladly be purchased from parts-manufacturing specialists, were they available.

In my opinion, such standardization can be brought about most easily if the manufacturer of parts prepare a complete catalog, giving dimensions and illustrations of the parts. In arriving at standards, the parts manufacturer should submit for approval by the various manufacturers designs and specifications he is prepared to furnish. We would be glad to submit drawings to the parts manufacturer of

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the standards at present used in our construction, for the purpose of facilitating the preparation of such a catalog, and we believe that other manufacturers will be glad to do the same.

Abroad there are a number of parts manufacturers who have gone into the matter thoroughly and have prepared catalogs giving complete information, from which a designer or purchasing agent for an airplane company can select standard designs which fit his purpose adequately. In this country, heretofore, no such facilities have existed. Such a catalog should be sent to the engineering and purchasing departments of every airplane company. A personal visit from a representative of the parts manufacturer, from time to time, for the purpose of keeping in intimate contact with the airplane manufacturers would be helpful.

In addition, it might be advisable to have the designs prepared by the parts manufacturer approved by both War and Navy Departments of the government, as well as by the manufacturers.

The S. A. E. standard for nuts and bolts most nearly approaches airplane requirements. Possibly a few amendments to this standard might be required for airplane purposes.

In preparing designs for submitting to the manufacturers, the only additional point that must receive consideration, other than would be covered in light-weight engineering design, is that of resistance, which must be studied closely and parts designed to reduce it to a minimum. This applies in particular to bolt heads, castle nuts, rod-end pins, and turnbuckles.

RELATIVE SAVING IN COST

R. M. Brown:—Standardization and the minimizing of the number of different parts on one airplane by making the same part perform different functions or take different loadings are two totally separate things that are often confused. While the reduction in cost through the use of the latter method may be great and the increase in the weight of the parts themselves very slight, the adjacent parts are generally affected and the machine consequently becomes heavy and inefficient.

True standardization comes only with quantity output of one design. The individual parts of one machine can be very different, save where the function is the same, and yet each part be standardized on all machines.

The airplane designer and builder will accept Mr. Diffin's recommendations on the standardization of bolts, pins, etc., in material and in head and nut dimensions for each diameter. This is true standardization and a step in the right direction. Limiting the numbers of different diameters and lengths, however, is not standardization and will result in increased weight and loss of efficiency in the airplane. Bolt diameters should run at least in thirty-seconds and lengths in quarters of the inch.

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The chief aim of standardization is to reduce the cost of manufacture and maintenance. It is obvious then that it should first be applied to the most costly parts of the machine. An analysis of a modern military airplane will show that the cost of all bolts, nuts and pins is less than one-half of one per cent of the selling price of the machine. The latest machine that my firm is building uses just under 700 bolts. The cost of these in 3½ per cent nickel steel with nuts is about $40.

The remainder of the metal parts on an airplane for the body, chassis, wing fittings and control units (exclusive of turnbuckles and wire) represents the greatest cost items of the entire machine, over twenty times that of the automatic machine products. These parts could be easily standardized. There are scores of different designs of wing-strut sockets, strut ends, box body clips, chassis fittings, axles and control operators. The best design for each should be selected, with the approval of the government officials, and made standard.

This standard fitting could be manufactured by a parts maker (or by the airplane manufacturer, if his business is large enough to warrant the special tools) in a variety of sizes and strengths suitable to any weight or type of airplane, in the same manner that automobile parts are furnished by a specialist in that line. It is my firm conviction that this method would reduce the cost of a complete airplane by more than 25 per cent. The advantage from a maintenance viewpoint is obvious.

CHAIRMAN SOUTHER:—About twelve years ago a great deal of work was done while establishing the A. L. A. M. thread, now called the S. A. E. thread, in determining how thick a nut should be and how much wrench-hold it should present.

CAUSE OF VARIATION AND FEASIBLE STANDARDIZATION

CHARLES M. MANLY:—In our company there have been possibly as many variations in lengths of bolts and sizes of heads as it is possible to find anywhere. A large part of that has been due to there being no standard to follow; each designer would therefore take something from his head. Very frequently we send men out to measure a part; one draftsman will report that a nut is ⅜ in. thick, another one 11/32 in., and possibly another fellow will say it is 13/32 in. thick. If each one of those men made a drawing and we had to reproduce the part in question, it is probable that each would have established a different thickness for that particular part. In a great deal of airplane work a part has been built first and the drawing made afterward. It is always that way in early development work. Sometimes it was left to the machinist as to just how thick he should make parts and then the drafting department was told to make the drawings conform to the machine. The next time a drawing was prepared the part was made by a different mechanic, and so a new standard was established.

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It has been suggested that we standardize the design of the crankshaft and that we standardize the design of the engine. I think possibly that is going a little too far; we want standardization in so far as it affects interchangeability between different manufacturers. It is very important that the propeller be immediately removable from one plane and put on another made by a different manufacturer. Therefore, I think we do not want to determine designs of basic parts or assembled units, but there should be standardization of screw machine parts, materials, gage of tubing and cold-rolled hexagon material.

The standardization of controls for airplanes is important as regards the war use of machines. It would be a great help if the distance between wing beams could be standardized, so that when a machine and the wing-beam fittings are damaged, we could transfer the wings from one machine to another. If in a year or so we could have not more than, say, ten distances between wing beams and only a few different styles of wing fittings, it would be of much help.

REDUCING STANDARDS TO PRACTICE

J. B. REPLOGLE:—After having standardized parts it will be necessary to start a campaign of education to insure that they will be used. We are assuming that the manufacturers are waiting with open arms to receive these standard specifications and immediately put them into practice.

I have been in pretty close relation with another field of standardization, in which a vicious circle has been created. I refer to machine screws, with all sorts of different kinds that can be called by the same name.

Some nine or ten years ago the American Society of Mechanical Engineers adopted specifications for standard machine screws. Previous to two years ago I could not buy from stock anywhere in the United States standard A. S. M. E. machine screws; that was when they had been adopted by the A. S. M. E. for seven years. I took the matter up with practically every machine-screw manufacturer in the United States and I asked:

"Why cannot we get these standard machine screws; they are good, are they not?"

"Yes."

"Why cannot we get them?"

"Nobody will buy them."

"Well, why don't people buy them?"

"They cannot get them."

CHAIRMAN SOUTHER:—Mr. Replogle has touched on a vital point, and I think the bridge across that ditch is the putting of the standard on the drafting board in some shape or other. The Society has made the attempt to do it in the S. A. E. Handbook and by other similar means. I doubt if any other society has gone as far, and I do not

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believe many of us would know where to go to find the accurate information needed to order A. S. M. E. machine screws to-day, that is, and do it easily. I believe that if the engineering books containing the standards adopted by the Society are placed on the draftsman's desk, they will be used.

CAPT. L. E. GOODIER:—The difficulty of obtaining non-standard nuts and bolts that might be used at the front is a matter that an aviator appreciates; that is especially true when he goes out into some of the smaller cities near which the aerial squadron is attempting to obtain bolts and nuts from stock; we cannot do it because they are special sizes. It is necessary to have a truck along that does nothing but carry a stock of steel and iron from which the special sizes can be made by the mechanics.

The aviator himself has the lack of standards impressed on him severely when he cannot get spare parts for fixing up a machine or for repairing breakage. He is the one who usually gets the brunt of the lack of standards, and he would be the man who would welcome such standards even more than the manufacturer of the airplane or the accessory manufacturer who supplies the special parts.

AUTOMOBILE AND AIRCRAFT ENGINE STRESSES

E. A. SPERRY:—There is nothing occult about standardization of anything employed in airplane manufacture. The automobile manufacturers are doing much better than they are ordinarily given credit for from the standpoint of the airplane-engine builder. In the automobile engine enormous stresses are introduced into the reciprocating parts under cold weather conditions. No airplane engine can ever be given that test, because it has a big propeller which cannot do over a certain amount without overloading the engine. A great deal of that abuse cannot be administered to an airplane engine, so I think we are ready to adopt a whole line of standards and depend upon the automobile engineers for the base line they have found as to thickness of nuts, strains on threads, and materials.

VALVE SIZES

ROBERT JARDINE:—For automobile and aircraft engines we have furnished 576 different-sized valves in the last two years. They vary all the way in size for a given horsepower from 3¼ to 1⅜ in. diameter. They vary as to size of stem from 5/16 to 9/16 in. I believe that 50 per cent of these variations could be eliminated.

It will always be difficult, I think, to obtain maximum efficiency from any engine if the designer ties himself down to standards, but possibly the gain that will result from the standardization will offset the loss of perhaps 10 per cent of the power.

Valves are designed, so far as we can tell, with no special reference to the material of which they are to be made. They design the valve first and then someone else says what it should be made of;

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oftentimes valves that are satisfactory in some materials are useless in others, so that standards of sizes of valves would have to be accompanied by standards of materials.

THREAD AND BOLT PRACTICE

L. G. NILSON:—Mr. Diffin said that it does not matter how far up a thread is cut on bolts because they invariably break at the first thread. It has been my experience that if the thread quits abruptly, a weak spot will result, but such is not the case if it is so made that the thread quits gradually. If care were taken in having the thread quit gradually, I believe the bolt would be more satisfactory.

J. G. VINCENT:—In laying out an airplane engine, I asked the Government for a recommendation as regards bolt sizes and threads and was simply advised, "Use S. A. E. threads." I went into the matter very thoroughly with the idea of using three sizes of bolts, ¼, ⅜ and ½ in., for the entire engine, outside of the bolts for holding the engine. I took the standard S. A. E. thread and also the bolt heads, but changed the standard and drilled all bolts up to the point opposite the end of the thread so as to give a cross-section area exactly equal to the cross-section area at the root of the thread. I therefore got bolts that were practically uniform in strength throughout their length.

Practically every nut on the airplane engine should have a cotter-pin anyway, so that I used only three nuts. The result is that in handling the engine a wrench to take only three sizes of nuts is required. There certainly should not be more than four sizes of nuts on the engine. It is my opinion, also, that what has been said about the nut is correct; a good high-carbon steel is plenty good enough for nuts. We are now having drawn a considerable quantity of hex stock that will come to us heat-treated.

We have found it practically impossible to heat-treat bolts and nuts after machining and get any kind of a fit. Nearly every one connected with aviation work specifies nuts called wrench-tight; that is, they cannot be screwed on with the fingers.

A. C. WOODBURY:—The situation in the aeronautic industry is different from that in any other line of work. Most of the planes purchased are for one customer; that customer is inclined to ask for standards; therefore, as his standards are adopted they will be put into effect.

A. P. BRUSH:—Three things are emphasized more strongly in aeronautic work than in the automobile industry: first, stability, because men's lives depend upon it; second, lightness, because the performance of the machine depends more on it than is the case in the automobile; and third, cost, because it is not material. Practically all the discussion of standardization has been along the lines of reduction of cost and greater convenience. The safety of the operator has not been considered as much as the convenience of the manufacturer.

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Mr. Vincent told of his method of drilling the bolts so that the cross-section above the thread is the same as the cross-section in the thread. It is a physical law that any tension bolt of given material and heat treatment is lighter and more reliable if the part of the section above the thread is reduced to correspond with the cross-section at the root of the thread. I believe we should recognize the standard that is a law of nature and should devote ourselves to standardizing the things that may be said to be in flux.

C. H. TAYLOR:—The customers who at the present time are purchasing airplanes in the largest quantities are the various governments. It is unfortunate that they seem to have conflicting ideas as to the different types of materials that should be used in different places. Entirely apart from standards of shape or form of, we will say, nuts, bolts and pins, we have a hard proposition in reconciling the various governmental demands. All of them seem to have a slightly different idea as to what material should be used, and it seems to me that if we establish a standard of material we will have to compromise more or less between the demands of the various governments.

AUTHOR'S CLOSURE

F. G. DIFFIN:—The principal point or the crux of the matter which I have endeavored to emphasize is this: The facilities for making airplane parts in this country are comparatively limited; in other words, the organization for the making of the parts is limited. There is an excessive demand for airplanes in this country to-day. If the United States Government needed 10,000 machines, it might as well ask for 10,000 moons. That is true because of the lack not only of bolts and nuts but also of other parts of the machines.

What we need is to standardize these parts. Each one is starting out with an arbitrary standard to-day, and if somebody does not standardize for them, a year from to-day we will have 10 or 50 standards and 50 different manufacturers will be making parts. Our biggest customer to-day is the Government—a condition that is likely to last for a long time. The Government will have to carry 50 different lines of supplies in every supply depot, and instead of one truck an airplane squadron will need many trucks to carry the parts.

We can deliver more bolts at less cost if we have some certain standards to follow. To-day that is not such an item, but in the future it will be. Price is a large consideration in most businesses, and it is certainly so with the United States Government, but when it buys airplanes the price is not so much of an object, because airplanes are badly needed. A year from to-day, or five years, the commercial possibilities in regard to the airplane will be far greater than they are now. The field to be supplied will be outside of the governments.

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SOME NOTES ON HIGH-PRESSURE AVIATION ENGINES

By Leigh M. Griffith

(Member of the Society)

In the endeavor to construct the lightest possible engines for aircraft, designers have in general followed one or the other of two tendencies in planning the design. The first, in point of time, is to assume large dimensions for the cylinders and work them at low gas pressures. This method permits a minimum section of metal for all parts subject to the stresses resulting from the gas pressures and also minimizes the difficulties of obtaining a satisfactory cooling system; it has been largely followed in the case of air-cooled engines, and in most such engines has been made necessary by the limited intensity of cooling action possible by the ordinary methods of direct air-cooling. The later and much more promising method is to use smaller cylinders and work them at the highest possible pressure, in the belief that this basis of design will ultimately lead to a considerably reduced weight per unit of power.

In the early days of aeronautic engines, in order to obtain any endurance at all worthy of the name, it was absolutely essential to adhere to the low-pressure type of design, since, entirely aside from the question of satisfactory cooling, it was impossible to obtain any ignition-means that would meet the requirements of aviation engines unless the gas pressure was kept low. This is well appreciated to-day since even now the greatest single source of trouble lies in the spark-plugs, which fail not so much because of oiling conditions as from insulation and electrode deterioration due to the combination of high and variable temperatures with gas pressures that also are high and variable. The low-pressure large-volume type of design received for a time an impetus from the almost exclusive success of the Gnome engine, which was of course a particularly shining example of such construction, as were also the early Renault engines. This was the line of least resistance and designers of new engines largely followed the example set by the designers of the two types mentioned.

EXAMPLE SET BY AUTOMOBILE RACING ENGINES

However, the experience obtained by those engineers who had been engaged in the design and operation of racing automobiles, the engines of which were at an early date limited in the maximum cylinder dimensions, showed that a satisfactory power-plant could be built using much higher gas pressures than the majority of aeronautic engine designers had thought possible. Also, some automobile companies with considerable racing experience assumed that it would be an easy matter to produce a satisfactory aviation engine by the comparatively simple method of slightly altering their successful

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automobile racing engines and decreasing their weight. While many of these latter did not succeed in producing anything permanent, the result was to bring into the list of engineers working on the aviation engine new men whose experience led them to adopt the high-pressure type of design.

HIGH AND LOW-PRESSURE ENGINES

I would place the dividing line between the high and low-pressure engines at about 100 lb. per sq. in. brake m.e.p. for the four-cycle type, and at about 75 lb. for the two-cycle type. Such a division would place the majority of the modern successful engines, especially of the water-cooled type, in the high-pressure class. Comparatively little has been done in the case of the two-cycle type, so that data for the discussion of this type are extremely meager. Nevertheless, I believe that this type offers considerable promise of eventually surpassing the maximum power-weight ratio that it is possible to obtain from the four-cycle type, owing to the apparent ease of obtaining brake mean effective pressures considerably more than half as great as in the case of the four-cycle type.

Without entering into a detailed discussion of the matter, it is true in general that for a given design of engine, operating at a given piston-speed, it matters little whether the power is developed in large cylinders operating under a low mean pressure or in small bore cylinders with high mean pressure. In either case, considering the effects of gas pressure alone, the stresses on all members below the cylinders and pistons are not affected by the difference in mean pressure, providing the total power developed is held constant. This is true because the constant piston-speed necessitates the total piston pressure also remaining equal, regardless of the piston diameter. This indicates that the cylinder is the principal element affected by any alteration of the brake mean effective pressure, the piston and valves being affected in a lesser degree. As the weight of the cylinders constitutes a considerable part of the total weight of any aeronautic engine (Winkler, the German authority, places the percentage at about 28 as a water-cooled engine average, which is 5 per cent greater than for the crankcase), it is believed that a consideration of the weight reductions possible of realization by the adoption of the highest mean pressures would be of considerable interest to designers.

If we assume that the maximum gas pressure bears a constant ratio to the mean effective pressure, as is at least approximately true, and we further assume, for the purpose of illustration, two engines whose mean pressures bear the relation of two to one, we see that the low-pressure engine must have twice the piston area of the high-pressure unit if they are to develop the same power at the same piston speed. This means that the low-pressure cylinder must have a diameter 41 per cent greater than that of the high-pressure cylinder. Working from the standpoint of the stresses resulting from the gas pressure alone, it follows that the annular cylinder-wall sectional-

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area must be the same for the two cases since the longitudinal load carried by it is equal to the total piston pressure, which is equal from the conditions assumed. The bursting load in the transverse direction, being taken by two thicknesses of the cylinder wall, requires a thickness in the case of the low-pressure cylinder of 71 per cent of that of the high-pressure one; this again works out roughly to the same cylinder-wall weight for the two cases.

While this reasoning indicates no weight saving for the high-pressure cylinder-barrel, it must be remembered that we are considering stresses resulting from the gas pressure alone, and that the thickness of cylinder walls required in practice is considerably greater than would be necessary to care for such stresses. The reason is that some extra metal is required to care for the distorting effect of the temperature differences in the various portions of the cylinder unit. The increase in thickness is necessary to give sufficient rigidity for the cylinder walls to retain their circular shape to a satisfactory degree. Considered from this standpoint, it would certainly seem inadvisable to make the thickness of the lower-pressure barrel any less than that of the high-pressure one, especially when it is remembered that its diameter is at the same time 41 per cent greater. In practice, the low-pressure barrel would probably be the thicker, owing to its larger diameter and consequent greater liability to heat-distortion.

DESIGN OF JACKET WALL

The jacket-wall thickness in a cast cylinder is more or less determined by the foundry requirements and would probably be somewhat greater in the case of the larger cylinder diameter. An applied jacket is also thicker for the large cylinder on account of the greater area of unsupported surface. Even with the same thickness of water space, the water weight would be less for the small cylinder, but as more heat has to be transferred per unit of area in the case of the small cylinder, the water velocity should be higher so as to provide a more energetic scrubbing action on the cylinder walls. This would require a thinner jacket space on the high-pressure cylinder, thereby further reducing the weight of the jacket water. The thickness of cylinder and piston heads would be about 26 per cent greater for the large low pressure unit; according to the Bach formula (for identical material, stress and design) this thickness varies only as to the cube root of the pressure but as the three-fourths power of the radius of the unsupported circular plate area. While this is not strictly true in practice, on account of these elements being generally of dome shape or ribbed, it at least serves to indicate that in the matter of weight engines of the small high-pressure type have the advantage.

THERMAL RESISTANCE OF CYLINDER WALLS

The enclosing walls of the combustion and expansion chambers must be considered also from another point of view than that of merely containing sufficient metal to resist the pressure and heat-dis-

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tortion loads. Inasmuch as about one half the total heat developed by the combustion of the fuel has to pass through these walls to the jacket water, it is necessary to consider the effect of this on the wall thickness. In the case of the high-pressure unit, we would have nearly the same total amount of heat to dispose of as with the low pressure unit, but, assuming a stroke-bore ratio for the former of two and the same stroke for both, the total wall area available through which to pass this heat would not be over 60 per cent as great for the high-pressure unit as for the other. Consequently, the unit intensity would be some 65 per cent greater, which would mean a higher wall temperature on the gas side and consequently a greater liability to preignition trouble, unless the cooling water was maintained at a correspondingly lower temperature, which would necessitate an increase in the radiation capacity.

The best method to counteract this difficulty would be to diminish the thickness, or rather the thermal resistance, of the walls in inverse proportion to the increase of unit heat-conduction capacity required. Such a method however involves the use of a higher grade of material for the cylinder walls and demands a greater attention to the problem of allowing the cylinder walls the greatest amount of freedom to expand in all directions under the influence of heat so that the minimum restraint is offered to such movement. It is this restraint that distorts the walls from their original form. It is also necessary to insure a more uniform cooling action of the circulating water, to the same end.

The use of a higher grade material is in itself a considerable advantage from the weight-reduction standpoint, but of course is equally applicable to the low-pressure unit. The use of automobile-type cast-iron cylinders for aviation engines, with either integral or applied jackets, is gradually but surely disappearing, for reasons that are well understood. Just now, the popular tendency is to use some form of cast aluminum-alloy cylinder with either a steel or cast-iron liner. This general type of construction is appearing in the individual as well as the block-cylinder form, but it seems to the author to be poorly adapted to the requirements of the really high-pressure engine because of the unavoidable fact that the total resistance to the conduction of heat through the walls is greatly increased by the discontinuity of metal at the joint between the liner and aluminum wall, and also by the considerably increased total thickness of metal. It would certainly appear that lubrication would be rendered more difficult and the risk of preignition increased from this cause.

A better arrangement, from the heat-disposal and weight standpoints at least, is that wherein the jacket water comes in direct contact with the steel liner. In the latter case, the liner can be screwed into the combustion chamber at its upper end so that the combustion chamber is a part of the aluminum block casting, or the liner can have a closed head-end forming the combustion chamber and with the valves

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seating directly on the liner material. In either case the cooling would be good, except at the screwed joint mentioned or at the points where the valve or spark-plug passages emerge, and where it is difficult to avoid an undesirably heavy section of metal that tends to accumulate heat.

The ideal cylinder would have the thinnest possible wall consistent with the maintenance of a satisfactory degree of rigidity; would be so designed as to permit the greatest freedom for expansion and contraction under the influence of temperature changes; would have uniform wall thickness throughout; and would be provided with a water-jacket of such design as to give a uniform cooling action over all parts of the cylinder wall.

The basic idea is to make sure that each unit area of heated surface of the combustion chamber and cylinder wall is separated from a like unit area of uniformly cooled surface by a wall of minimum uniform thermal resistance. Of course, in the case of the piston and valve heads this cannot be done, since these members have to conduct the heat they receive largely to their surfaces of contact with the cylinder metal, in order to transfer it to the cooling water. In the piston, this is best accomplished by using a metal of high conductivity and a design that provides ample sectional area to properly conduct the heat from the head to the skirt, from which it passes through the oil film to the cylinder wall.

PROPER PISTON MATERIAL

An aluminum alloy is by far the best material to use for high-pressure piston construction, chiefly because of its high heat conductivity —some three to four times as great as that of either cast-iron or steel —but also because its low specific gravity brings about a considerable reduction in the reciprocating weight and inertia forces. Attention has been called to the necessarily high rate of heat absorption in the case of the high-pressure unit, but this is almost offset in the case of the piston by the reduced diameter and consequently reduced distance for the heat to travel.

The inlet valves will give no troubles due to over heating if of ordinary conventional design, as the incoming charge serves to keep their temperature well below the troublesome point. The exhaust valves however are a prolific source of trouble, owing to their being in contact with the hot gas for such a large proportion of the cycle. For high-pressure units, these valves must be kept much cooler than for low-pressure ones, and since all the available valve-head materials have about the same thermal conductivity, the only means at hand for keeping the temperature low is to use small diameters, thick heads, large well-guided and cooled stems, and fairly wide seats on a well-cooled surface. All of this will tend to increase the valve weight and will lead to the more extensive use of four or more valves per cylinder.

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The one best solution of the problem of the proper cylinder construction for the aeronautic engine working under the highest brake mean effective pressure is that in which the cylinder units are built up in pairs or blocks from steel parts flame-welded together into one integral whole. A number of advantages are inherent in this form of construction, such as the following: the absolute minimum thickness of metal is required to resist the stresses due to the pressure and thermal effects, thus decreasing the weight; the minimum thickness of metal wall interposed between the hot gases and the jacket water and the absence of masses of metal tending to accumulate heat, resulting in uniform and effective cooling of all interior surfaces by water of fairly high temperature; assurance of the homogeneity and character of the material composing the cylinder elements; a definite knowledge of the form and thickness of all walls; the greatest facility of inspection and testing of all joints during the assembling operations,—all of which make unnecessary any arbitrary addition of metal in the endeavor to allow for possible unknown weaknesses.

WEIGHT REDUCTION WITH BEST CYLINDER CONSTRUCTION

As showing the weight-reduction possibilities of this construction, the author will say that he has built 4⅝ by 7-in. cylinders by this method, of nickel and carbon steels, in pairs, that weighed only 24 lb. per pair, or 9.8 cu. in. displacement per pound of weight. These cylinders are on an engine that on official test showed a brake mean effective pressure of more than 116 lb. per sq. in., which is believed to constitute a record for aeronautic engines. The hydrostatic test-pressure for inspection was 1000 lb. per sq. in. Moreover, the cylinders were provided with four valves and two spark-plugs each and the jacketing was very complete, even extending to the inlet and exhaust flanges as well as completely around the valve-seats and plug bosses. The fact that these light cylinders were able to withstand the high temperature and pressure without distress or heating troubles, certainly proves that it is absolutely unnecessary to adopt the heavy constructions for these conditions.

In comparison, it may be stated that the 4⅞ by 7-in. cast semi-steel cylinders of a recently announced aeronautic engine weigh 51 lb. per pair, or 5.1 cu. in. displacement per pound, without the cast aluminum covers that close the jacket spaces; and this is only a two-valve engine. Another airplane engine, also recently announced, has built-up steel cylinders with cast aluminum jacket covers; the 4 by 6-in. cylinders weigh 40 lb. per block of three, or 5.65 cu. in. displacement per pound. This also is a two-valve design. Both have been described recently in the technical press.

Insofar as the effect on the type of cylinder construction employed is concerned, it matters little whether the engine is laid out as a geared-down short-stroke job or a direct-drive long-stroke, except for the comparatively slight saving due to the shortened barrel length in

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the first case. However, the author has become convinced that the greatest power-weight ratio can be obtained in the direct-drive engine. This is borne out by the fact that the lightest water-cooled engine so far officially tested, to the author's knowledge, is the one incorporating the above-mentioned light-weight cylinders. At the moderate speed of 1325 r.p.m. this engine showed a weight of only 2.65 lb. per brake horsepower, this including the two magnetos complete with all wiring and plugs, the two carbureters and manifolds, all water headers and a particularly powerful pump. However, it did not include the weight of the propeller-hub, starting-crank, exhaust headers, or the contained water and oil. It would seem that the most simple and direct method to obtain a sufficiently high piston speed in combination with a propeller speed that will come within the zone of high propeller efficiency is to adhere to the long-stroke direct-drive design in which the propeller is carried on an extension of the crankshaft. Certain it is that the total inertia forces of the reciprocating parts for this method are less by a considerable amount than those in the shorter-stroke geared-down engine.

BETTER SPARK-PLUGS NEEDED

Spark-plugs are perhaps the greatest source of trouble in the high pressure engine. If the threaded portion of the shell makes good contact with a well-cooled surface, no trouble is to be expected from the shell itself over-heating. However, the grounded electrodes must be of sufficiently high heat conductivity and must have a sufficiently good thermal contact with the shell to ensure that the heat they receive will be carried to the shell and then to the jacket water. The sectional area of these electrodes should increase from the sparking point to their anchorage in the shell, and they should not be flattened or deformed so as to offer a relatively large surface for the absorption of heat from the gas. The center electrode usually gives the most trouble from overheating, and this is to be expected since the heat received by it has to be in a large measure conducted through the insulator to the plug shell. Very little heat is conducted to the air lengthwise of the stem, owing to the small size and length of this member. Perhaps this situation can be helped by the development of an insulating material having a higher heat conductivity in proportion to its electrical conductivity than the materials now in use, but greatest improvement is rather to be looked for along the lines of electrodes with higher heat conductivity, greater sectional area, and perhaps thinner insulators having more intimate contact with both the electrode and shell. The recent idea of introducing a small amount of air or mixture direct to the plug cavity, in such a manner that it washes both the center electrode and insulator, may prove to be a considerable aid.

In an engine developing a high mean effective pressure, a high volumetric efficiency and a high compression pressure are necessarily required; these in turn demand efficient cooling, scavenging, charging

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and ignition. The cooling requirements have been mentioned and consist fundamentally of the uniformly energetic circulation of the cooling water over a cylinder wall of the highest possible uniform thermal conductivity. The thorough scavenging required in the high pressure unit is aided by the high compression ratio, which implies a small compression chamber to retain the residue of the burnt gases. Both scavenging and charging-betterment demand ample gas passages of minimum resistance, which can be best obtained with multiple valves opening into stream-line ports of the shortest length and least turns. All of this is well understood, except the necessity for more than two valves.

ADVANTAGE OF MULTIPLE VALVES

The author believes that only by the use of multiple valves of moderate diameter can we get the highest volumetric efficiencies and compressions at the same time, since the extreme difficulty of keeping the center of large exhaust-valve heads sufficiently cool to eliminate preignition with the high compression will compel the adoption of the small valve. In the case of the inlet valves, ample area of gas passage is of greater relative importance because of the very low pressures available to produce the gas flow. This ample area is more easily attained with the multiple valves. In addition, the latter arrangement tends to reduce the inertia of the valve system.

Ignition for the high-pressure engine demands far greater attention than for the low-pressure unit. The increase of compression increases the rapidity of inflammation somewhat, and the reduced size of the compression chamber further shortens the time of total ignition, yet in order to obtain the highest rapidity of inflammation required for the development of maximum mean effective pressures, it is necessary to ignite the mixture simultaneously from two or more points as widely separated as possible. This should preferably be done by separate and distinct ignition apparatus, because of the greater reliability afforded by such an arrangement. Spark-plugs should be so located as to receive the maximum cleaning and scouring effect due to the passage of the incoming charge over the plug electrodes, both on account of the cooling effect on the electrodes and insulator and in order to insure that the plug cavity is filled with fresh mixture that is circulating with the greatest turbulence. Care must be taken that plugs are so arranged that these actions are as near alike for all plugs as is possible, in order to insure synchronism in the ignition.

DISCUSSION

ROCKER-ARM VALVE MECHANISM

E. PLANCHE:—I have followed with great interest the developments in airplane engines in the past year, and in looking over the various papers that have been submitted to the Society on the sub-

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ject, I have not seen any reference made to the best design for the valve-gear mechanism. It is a very important subject and has not been given the attention it deserves.

From my own personal experience, and from the experience of engineers abroad, I can state positively that no valve mechanism in a flying machine engine should be driven by a rocker-arm system, that is, the action of the camshaft in opening and closing the exhaust and inlet valves should not be transmitted to the valve through any system that uses a rocker-arm.

They were also confronted by the fact that the valve seats were not properly cooled. The valves became red hot after a few hours of running and broke down. It is absolutely essential that the valve seats, especially the exhaust valve seats, be made uniform in thickness with the rest of the explosion chamber and be cooled all around properly and evenly.

It is useless for us to build engines on a principle that on the other side has been absolutely demonstrated to be wrong. The driving of the camshafts on the top of the cylinders requires a number of idle gears, but in mounting all those gears on ball bearings and making them of a high grade of alloy steel, the noise being only a secondary consideration, a successful drive can be obtained.

CHAIRMAN MANLY:—We have seen many engines run for fifty hours continuously, the rocker-arms remaining good at the finish of the run, and a fifty-hour run repeated immediately after that and the rocker-arms continuing good. In fact, if airplane engines did not give any trouble on any other score than rocker-arms I think we would sleep well at night.

LIMITING FACTORS OF ENGINES

J. G. VINCENT:—Two things are critical in the design of the high efficiency engine of fairly large power. The piston used to be a critical point, but with the modern aluminum alloy piston we have overcome that trouble, for the time at least. The heating of the exhaust valve and the failure of spark-plugs are the two things that really limit us today. The steel-cylinder construction can be such as to aid in cooling the exhaust port. What we want to do is to keep the valve stem as cool as possible; on the exhaust side there is no particular advantage in keeping the part of the port directly back of the valve stem clear. So, if the steel barrel is made, we will say, in one main forging and then machined out with little short nubbins on the ports, the main ports can then be machined out separately and then screwed in and welded. By using this construction we can bring the water down close to the stem and in that way get the maximum amount of cooling on the valve.

The spark-plug presents the greatest problem we have today. A number of people are working on it, and I feel confident that some

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one will give us a spark-plug in six months that will make some other part of the engine the limiting factor.

I believe that the gear-driven propeller is the best, because in the geared construction the engine speed can be as high as the gear will run and run continuously, and still a propeller speed as low as may be wanted can be obtained. I am told that the best propeller speed varies considerably with the type of plane that is being driven, and that in the large planes for carrying loads it is desirable to have it as low as 900 or 1000 r.p.m. If that is true it is certainly a tremendous handicap to keep the engine speed down to that point; with the geared construction we can just as well have 900 or 1000 as 1400 or 1500 r.p.m., it being possible to provide several sets of gears that will give anything from 900 to 1400 r.p.m.

We have done a great deal of experimental work during the past year on valve mechanism; I built some small, high-speed engines running as high as 4000 r.p.m. in order to test the overhead rocker-arm valve mechanism. There is nothing radical in that engine, except in the method of getting the oil into the camshaft housing. The engine required 60-lb. valve springs with the valves closed, equivalent to about 74 lb. with the valves open. We have run it continuously on the dynamometer at times for 300 hours. On our big airplane engine, which runs at 2150 r.p.m., we only have 29-lb. valve springs. That difference is not quite as great as it looks, because the larger valve in the larger engines has more inertia to overcome, and that probably imposes more strain on the rocker-arms than the figures indicate. I believe that with the direct-operating valve it is necessary to inclose all the valve mechanism. I do not believe this is advisable on an engine that is supposed to run continuously at high speed.

One of the disadvantages of rocker-arms is the side-thrust on the valves and stems. It is extremely important to have the valve stems and guides made of proper material. So far we have obtained the best results with a cast-iron guide on a tungsten valve. That will wear out after awhile or wear so that we want to change it, but we have had absolutely no failures through breakages or sticking. When we attempted to use straight steel on stems and guides we had considerable trouble. They would last only a few months. There is a limit in the power of an engine beyond which we cannot go and obtain really high efficiency and long life; of course, that argues for many cylinders for a high-power engine.

We have tried reducing the angle between cylinder blocks of our engine. We cannot tell the difference between 40 and 60 deg. in a twelve-cylinder engine. From what I have been told of aircraft requirements it seems desirable to have the engine as narrow as possible, offering a minimum head resistance.

QUARTZ SPARK-PLUG INSULATORS

DR. R. H. CUNNINGHAM:—Has any one utilized quartz as the dia-

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lectric of the spark-plug, and is it possible to get quartz in all shapes and forms? Quartz is a substance that one can heat red hot and drop in water without cracking it. Its coefficient of expansion is not extremely high, but, protected by suitable metals or copper gaskets, quartz offers great possibilities.

DR. H. C. DICKINSON:—The Bureau of Standards has been spending considerable time in investigating the subject of spark-plugs. The question of using quartz has been discussed, but as yet we have not secured any quartz insulators to try. It is a question, however, whether the electrical properties of quartz will be as good as those of porcelain. We have discovered a number of peculiarities in the behavior of porcelain insulators, and we are trying to find out what is back of it all. We have found out what takes place when the insulator is overheated. We are trying to find out why it takes place and also to develop new types of porcelain without the faults of those at present in use.

We have had considerable to do with the problem of carrying heat away from places, and it is possible that the water circulation in the jacket may merit considerable more discussion than it has received. It is a fact that most of the drop in temperature of the cooling water takes place at the surface of the metal. There is comparatively little difference between an eighth and a quarter of an inch of metal when the circulation of water is fairly slow, as it is in most of the cooling jackets. Therefore, possibly a further consideration of the distribution of water, both as to rate of circulation and as to order of circulation, would be useful.

J. H. HUNT:—Porcelain when very hot becomes a conductor, although there is no mechanical rupture. It is possible to heat porcelain or any glass and send a current through it without injuring it, in such a way that after it is cold it is just as good an insulator as it was before. I feel sure that is as true of quartz as it is of porcelain.

DR. R. H. CUNNINGHAM:—The insulators do not become good conductors or thorough conductors until they are very hot, and the ordinary heat of the charge scarcely affects quartz at all. In our efforts to work it we have to use the oxy-hydrogen burner.

If the quartz or porcelain became sufficiently heated to permit sending the current through it, preignition instead of failure of ignition would occur. It is possible that the nickel-steel electrode will become red-hot. That may cause preignition, and often the expansion of the electrodes causes cracking of the porcelain; at certain temperatures porcelain becomes more or less a conductor of the high frequency currents that are developed by some electrical apparatus employed for ignition.

DR. H. C. DICKINSON:—If the ordinary porcelain insulator is heated at ordinary pressures of the air, the first thing that happens is that on reaching somewhere around 200 to 400 deg. C., which is a

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moderately low temperature, the porcelain does not become a conductor, but a brush discharge takes place over the surface. If the pressure is increased the temperature of the brush discharge is also increased, and therefore the porcelain will attain a higher temperature before failing in that way. But, judging from our experience with pressures up to about 200 lb., the failure is nearly always due to the brush discharge over the surface rather than to the leakage through the conductor itself. It is evident if that is what happens then that the form of the ignition current is also involved in the question of failure, and that is a thing that must be studied before we can arrive at any definite conclusion.

ENGINE LIMITATIONS

H. P. MAXIM:—I have been using a 100-hp. flying boat for the past year, and I have not had a failure due to exhaust valves. I have had considerable trouble with spark-plugs, but we have had still more trouble with piston-pins. We cannot fly more than two or three hours steadily before we have got to come down—something the matter.

The trouble occurs not altogether because the porcelain becomes a conductor at high temperature or because the exhaust valve or an exhaust-valve stem sticks. I think it is because we have not yet built those engines well enough.

A. LUDLOW CLAYDEN:—It is probable that Mr. Maxim's trouble with piston-pins is due to too much heat in the wrong place. Just as in other engines, the trouble is due to exhaust valves, or perhaps in most to the spark-plugs.

The reason it is more difficult to make an airplane engine run more consistently than an automobile engine is that the average temperature in the cylinder is a great deal higher. I assume it is at least twice as high under ordinary conditions, and that being so everything is working under conditions twice as hard to meet.

I was interested in the quartz plug suggested, because I received a wonderful story about three months ago to the effect that the French engineers were using quartz spark-plugs in Gnome engines. I was unable to prove it or disprove it.

W. B. STOUT:—The problems mentioned can be solved by cooperation, and the fact that so many large organizations are getting into the industry and attempting to build engines and even airplanes will mean a tremendous advancement in the art.

J. G. VINCENT:—The Champion Spark Plug Company at Flint has made some quartz plugs for me. They were fairly successful, but the great difficulty was in getting the quartz and working it. From what were built by hand we could not determine really whether the quartz was any good.

The steel cylinders of our large engine are 4 by 6 in., and are of ample length. The piston is guided properly at all times, even in a 6-in. stroke. The two valves are 2 in. diameter in the clear, with

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30-deg. seats. The cylinders are in blocks of three each. Those blocks of three each weigh 37.5 lb., complete with the valves, valve springs, guides, collars and keys and everything, exclusive of the camshaft.

We made some very similar steel barrels with cast aluminum jackets around them. The steel barrel extended up only just above the valve seat and the rest of the port was cast aluminum, as was also all the head of the jacket. No aluminum was cast around the barrel, except just at the top and where the jacket is attached. The lowest weight we could get with that construction was 42 lb. per block.

There are many difficulties in the manufacture of steel cylinders. The difficulty is almost entirely, however, in the welding of the steel jacket. In our opinion it is a matter of design and selection of material. We have not learned all about it yet, because we are having some trouble, but we are confident that we are on the road to success.

OVERHEAD CAMSHAFT DRIVES

There are many different ways of driving overhead camshafts. The first time I laid out a spur-gear drive it looked complicated and heavy. After I designed that first drive I went ahead to make it, and not being satisfied I laid out a bevel-gear drive. A bevel-gear drive can be laid out for extremely light weight if the engine is very simple, like some that have no generator or starting apparatus, but if provision is made for driving a generator and two magnetos and a distributor system it is necessary to have too many drives. I found that the weights of the bevel gears and of the bearings that had to be used to take the thrusts are considerable, for the arrangement that looks the simplest weighs the most. There are seventeen spur gears in the drive of our engine, and something like thirty ball bearings. The total weight of the whole drive is 17 lb., compared, as I remember, with about 19 lb. in the bevel-gear drive.

We anticipated trouble with cooling the reduction gearing, and laid out an elaborate system for flooding with oil. We also anticipated that there would be more loss than actually occurred. From some very rough tests we learned that the loss is less than 3 per cent. Those gears are 2 in. wide and they are transmitting from 212 to 240 hp. in the various designs. We notice absolutely no tendency to heating up. Of course, they are mounted on generous bearings and there is little friction. At 1400 r.p.m. our engine developed 180 hp. with direct drive; with geared drive it can develop 225 hp. just as easily; in that case the propeller would run anywhere from 1000 to 1400 r.p.m. The complete propeller-shaft, gears and all bearings weigh 74 lb. which must be added to the weight of the engine, of course, to offset partly the increased horsepower. I cannot see how the direct-drive engine can ever compete with the gear-driven one as far as maximum horsepower is concerned.

CHAIRMAN MANLY:—One of the most interesting things I noticed

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in the German engines I saw in Europe last summer was that the welding on any one cylinder was as uniform as the welding on any other cylinder. They seemed to be absolutely uniform. It would certainly be worth a great deal to us if some people in this country would either develop the men or the teachers of the art of welding that would enable us to acquire that degree of skill the German workman has certainly acquired in the welding of steel jackets on cylinders.

AUTHOR'S CLOSURE

L. M. GRIFFITH:—Mr. Vincent's method has considerable value for cooling the exhaust-valve guide, but I think it affects very little the amount of heat withdrawn from the center of the valve head to the stem. The larger percentage of the heat goes through the seats.

The coefficient of expansion of quartz is only about one-sixteenth that of porcelain, so that it would be impossible to maintain any thermal contact between the outside of the quartz insulator and the inside of the spark-plug shell. If it was tight when cold some kind of follow-up spring would be necessary to carry heat from the quartz to the jacket water. The center electrode could be taken care of by making it out of some alloy that did not expand, thus maintaining good contact between it and the quartz.

When there is considerable metal between the plug and the water there is much probability of the plug overheating under pressure conditions that would not cause such trouble at all, provided the plug was of less thermal resistance or there was less thickness of wall between the shell and the water. Of course, the drop in temperature between the water and the plug shell is largely at the surface of the jacket. That temperature drop can be increased by a rapid circulation of water, a sort of scrubbing action. The velocity of water over surfaces from which considerable heat has to be withdrawn necessarily has to be higher.

I could not find any material that would stand the temperatures that the plug electrode attains, owing to the impossibility of conducting the heat lengthwise or through the insulator. It would simply melt off the end. I do not know whether it is entirely a matter of material. A scheme is being advertised now in which a small amount of air or the mixture is introduced into the cavity around the insulation of the plug itself, with the idea of cooling the insulator and the center electrode. Cool air can be introduced from the outside or the mixture can be taken from the manifold. If the latter practice is followed the entire plug cavity is filled with a quick-firing mixture, probably increasing the rate of propagation of the flame.

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SUGGESTIONS FOR STANDARD TESTS OF AIRPLANES

By Jno. J. Rooney

(Junior Member of the Society)

One of the most serious questions confronting the airplane industry at present is: how can performance predictions be made more reliable? The importance of being able to predict the performance of a design with precision is brought home to us when we are informed that, during the past year, manufacturers have had considerable difficulty in obtaining with their machines the performance guaranteed to the Government in their contracts. This last feature is in itself serious, because it means not only much expense to the manufacturer but also delay in the delivery of the machines to our Army and Navy, a condition, which, if prevailing during war time, would be a national calamity.

A brief analysis of some of our present methods may throw light on the causes of our trouble and possibly show us a solution of the problem.

PROCEDURE NOW FOLLOWED

The policy of the industry, generally, is to start the development of a new design by doing all the preliminary work in the best approved scientific manner. Laboratory tests are usually conducted with the highest degree of precision and the same scientific thoroughness is carried out in all the engineering work until the actual field testing is done, when carelessness occurs.

It seems that it is the policy of some of the manufacturers to force successful performance regardless of the number of alterations in design required for the accomplishment. It is my opinion that in this particular we are making a grave mistake. The testing field is nearly always located some distance from the factory and the engineering staff; it is therefore impossible for the engineers to supervise all the changes that are made on the field and investigate the resulting difference in performance. Reliable records of engineering value are seldom kept on the field, and as a result the engineers are deceived regarding the performance of the machine: first, because they do not learn the truth about the performance; and, second, because they have no record of the changes that have been made on the machine to make it come up to expectations—changes often important enough to alter radically the original design.

This means that when the next airplane is designed the same mistakes are made and the same slip-shod field methods are employed in making corrections that would have been incorporated in the design if the engineers had had accurate information as to their advisability.

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CONDITIONS DETERMINING PERFORMANCE

We shall now consider some of the ways in which an airplane's performance can be affected. Two conditions affecting performance that are more or less uncertain and are capable of wide variations are the weather and the skill of the pilot. The effects of varying weather conditions are obvious. The effect of the personal equation can best be shown by citing actual conditions. The low speed of an airplane varies inversely as the magnitude of the angle of attack (that is, for all flying angles), therefore, the higher the angle, the slower the speed. By being able to take advantage of this peculiarity a skilful pilot can land a machine at a lower speed than can an amateur. The skilful pilot can also obtain a higher maximum speed and a better climbing rate by being able to take advantage of other similar peculiarities.

The speed of an airplane is a function of the wing shape and loading and is due to the thrust overcoming the resistance. The power developed by the engine depends on a number of different conditions. The performance of the propeller also depends on several variables. Therefore, since the performance of an airplane can be affected by so many variables it is preposterous for us to think we can continue conducting field tests in an unscientific way and at the same time make progress as rapidly as we should.

IMPROVEMENT IN MAKING FIELD TESTS

What I have to suggest is that we standardize field tests as much as possible. The automobile engineers have found it necessary in the development of their engines to have a complete record of all the changes they make in design and the effect they have on the engine's performance. As a result, they can predict with a high degree of accuracy the result of this or that change. In order to facilitate the recording they have evolved standard forms that contain all the important data they desire to record. Since they have already accomplished much by these methods, we should profit by their experience and conduct our tests in the same scientific manner.

Standard Test Forms

Outlines of forms for airplane (I), engine (II) and propeller (III) specifications and for recording airplane performance data (IV) are given later in this paper. The specifications should be separated, as shown, to eliminate the necessity of having to rewrite the complete set in case only one of the units is changed.

The sheet proposed for the S. A. E. Engine Testing Forms seems satisfactory for giving the engine specifications. This sheet and the accompanying directions are therefore reproduced. Form IV is proposed for recording test data. I have endeavored in this to include all the important observations obtainable with present instruments.

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VALUE OF FLIGHT REPORTS

The forms outlined are primarily for the manufacturer's use on the test field, but at the same time they should also be used on all aviation fields, especially on those belonging to the Government. The owners of aviation fields are in a position to collect much valuable engineering data and we should solicit their cooperation. By a little effort on the part of the testers at such fields the manufacturers can be furnished with reports on the performance of particular models under all kinds of conditions.

Our sad experience in Mexico last summer is enough to show the importance of knowing the conditions under which machines are to be flown. We should have reliable data on the climate and soil of every section of the United States, as these two conditions may at some time completely determine the design.

At present performance tests cannot be conducted as scientifically as we hope they will be in the future, owing to lack of proper instruments. The present instruments are nearly all non-recording, and are usually separate, which means that simultaneous readings are impossible. In some work, particularly in propeller designing, it is necessary to know the simultaneous velocity of advance, revolutions per minute and power absorbed. If correct values of these quantities are not known propeller designing is mere guess work.

An ideal arrangement of the instruments would be to mount them in one case and have one clock operate a recording device. If such a combination is not practical we should at least try to develop a recording air-speed indicator and tachometer, if for nothing more than to check our propeller computations.

AUTHOR'S CONCLUSION

Performance predictions can be made more reliable by satisfactorily checking our laboratory experiments with actual field tests. Whether we use the plan outlined above, or some other to furnish that check, let us by all means increase the value of our field tests.

I—Suggested Form for Airplane Specifications

Manufacturer .....
Model ..... Serial No.....
Side Elevation—Drawing No.....
Front Elevation—Drawing No.....
Plan—Drawing No.....

Type

Tractor or Pusher.....
Land or Water.....
Planes, No.....
Planes (Position) .....
Engines, No.....
Propellers, No.....
Engines (Position).....
Propellers (Position) .....
Body (Kind) .....
Landing Gear (Kind).....

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Areas

Upper Wing (Excl. Ailerons).....sq. ft.
Middle Wing (Excl. Ailerons).....sq. ft.
Lower Wing (Excl. Ailerons).....sq. ft.
Ailerons .....sq. ft. each.....sq. ft.
Total Supporting Surface.....sq. ft.
Rudder .....sq. ft.
Tail .....sq. ft.
Fin .....sq. ft.
Elevator .....sq. ft.
Skid Plane .....sq. ft.

Weights

Dead Weight .....lb.
Useful Load:
Pilot .....
Passenger .....
.....hr. fuel at.....lb. per b.hp. hr.....lb.
.....hr. oil at.....lb. per b. hp. hr.....lb.
Other Weights .....lb.
.....
Gross Load .....lb.
Load per sq. ft. of Supporting Surface.....lb.
Load per b.hp. of Engines.....lb.

Design of Wings

	Upper	Middle	Lower
Aerofoil	.....	.....	.....
Mean Span, ft.....	.....	.....	.....
Mean Chord, ft.....	.....	.....	.....
Dihedral Angle, deg.... ...	.....	.....	.....
Angle to Engine Shaft, deg..	.....	.....	.....
Area, sq. ft.....	.....	.....	.....
Spars, No.....	.....	.....	.....
Sweepback, ft.	.....	.....	.....
Stagger, ft.	.....	.....	.....
Mean Aspect Ratio.....	.....	.....	.....
Gap to Chord Ratio.....	.....	.....	.....
Rake, deg.	.....	.....	.....

Body

Type .....
.....
Length from Nose to Stern Post.....ft.
Breadth (Max.) .....ft.
Depth (Max.) .....ft.
Stern (Vertical or Horizontal).....
Weight (Bare) .....lb.
If Boat:
Displacement .....cu. ft.
Planeing Area .....sq. ft.

Landing Gear

Type .....
.....
Wheels or Floats, No. .....
Gage .....ft.
Wheels .....in. dia.....in. width

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Floats .....ft. max. length.....ft. max. width
Float Displacement .....cu. ft.
Struts, No. .....Kind .....
Wing Float, Size.....ft. max. length.....ft. max. width
Weight .....lb.
Displacement .....cu. ft.
Tail Float, Size.....ft. max. length.....ft. max. width
Weight .....lb.
Displacement .....cu. ft.

Controls

Type .....
Angle of Tail Plane to Engine Shaft.....deg.
Ailerons, No.....
Position .....
Rudders, No.....
Position .....

Center of Gravity

Horizontal Coordinate Measured from.....in.
Vertical Coordinate Measured from.....in.

II—RULES AND DIRECTIONS FOR USE OF SPECIFICATION SHEET

(See corresponding numbers on sheet, page 199)

(2) Piston displacement, see tables, S. A. E. Handbook, Vol. I, sheets 42-421.

(3) The compression volume is the volume occupied by the charge when the piston is at the top of the compression stroke. To measure this volume, with the piston on dead center at end of compression stroke (with both valves closed) fill the compression space from a graduate containing a known volume of light oil or kerosene. Care must be taken to correct for leakage. Total volume of cylinder = piston displacement + compression volume. Give compression pressure at 100 to 120 r.p.m., or at speed of standard starter.

(4) State number of cylinders cast integral, whether offset, type of cylinder head, whether water space is provided between adjacent cylinders.

(6) State whether water or air-cooled. If the former, state whether pump or thermosyphon. Note if two pumps or thermostat are used. State type of pump.

(7) Weight of piston with rings and pin should include weight of bushings, screws, or other piston-pin fastening devices in the piston. Record all weights in pounds and decimal parts thereof. In measuring length of piston and distance from center of pin to top of piston, deduct any chamfer or crown at top of piston.

(8) Specify whether rings are concentric or eccentric; give name, sketch or description of special types. If oil-ring is used, state location.

(9) In giving weight of connecting-rod, include weight of all bushings, bolts, screws, and oiling devices normally attached to the rod. For piston-pin see (7). The connecting-rod must be horizontal while the ends are being weighed, the ends being supported by knife-edges or arbors. For V-type engines, state lower end construction.

(10) Under location, state whether in connecting-rod or piston.

(12) Diameters and lengths of bearings are to be stated in order from front to rear.

(14) Describe contour of cam, such as, uniform acceleration, tangential.

(15 and 16) In case of non-poppet valves describe and give dimensions.

(17) Reciprocating parts of directly operated poppet valves include valve, valve-lifter, valve-spring retainer and lock, and half of valve-spring.

(19) To determine valve-timing, mark top and bottom dead centers on flywheel rim; also points at which each valve opens and closes, engine cold and tappets set for standard clearance. Measure with flexible steel tape the length of arcs thus marked on flywheel. Reduce to degrees. Check both top and bottom dead centers for engines with offset cylinders.

(20) Moment of inertia of the flywheel is to be given in mass (weight in pounds ÷ 32.2) and foot units. Moment of inertia is equal to the mass multiplied by the square of the radius of gyration. $I = M R^2$.

(21) The complete weight of engine should include oil, water, and all mechanically attached units necessary for normal functioning of engine, such as carbureter and its attachments, magneto, ignition distributor, generator, starting motor, fan and governor. Do not include such accessories as horn, tire-pump and vacuum tank. List weight of each item separately.

(24) State if heated by water or exhaust, and whether part or all of the air entering carbureter is heated.

(25) Under "general principles of operation" give description; as: "Ven-

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turi type with single adjustable nozzle and single auxiliary air-valve with one spring;" "straight-tube type, four non-adjustable nozzles coming into operation successively as air-flow increases."

(26) By description and sketch, give general form, approximate inside

S. A. E. ENGINE TESTING FORMS—SPECIFICATION SHEET—B

Name and Model _____ Date of Test _____

Manufacturer _____

*(1) General Type _____ Cycle _____

(2) No. of Cyls. _____ Bore _____ in., Stroke _____ in., Piston Displ. per Cyl. _____ cu. in., Total _____ cu. in.

(3) Compression Vol. (V_c) _____ cu. in., Total Vol. of Cyl. (V) _____ cu. in., Compression Ratio = $\frac{\text{Comp. Vol.}}{\text{Total Vol.}} = \frac{V_c}{V} =$ _____

Compression Pressure _____ lb. gage at _____ r. p. m.

(4) Type of Cyl. Casting _____ Matl. _____

(5) Type of Valves _____ Location _____

(6) Cooling System _____

(7) Piston, Type _____ Matl. _____

Wt. with Rings and Pin _____ lb., Length _____ in., Distance Center of Pin to Top of Piston _____ in.

(8) Piston-Rings, No. per Piston _____ Type _____ Width _____ in.

(9) Connecting-Rod, Type _____

Length, c. to c. _____ in. Weight, Upper End _____ lb., Lower End _____ lb., Total _____ lb.

(10) Piston-Rod Bearings, Diam. _____ in., Total Length _____ in., Matl. _____ Location _____

(11) Connecting-Rod Bearings, Diam. _____ in., Length _____ in., Matl. _____ Type _____

(12) Crankshaft Bearings, No. _____ Diams. _____

Material _____ Lengths _____

(13) Camshaft Bearings, No. _____ Diams. _____

Material _____ Lengths _____

(14) Type of Cams _____ Type of Valve-Lifters _____

(15) Inlet Valves, No. per Cyl. _____ o.d. _____ in., Port Diam. _____ in., Lift _____ in., Seat Angle _____ deg.

(16) Exhaust Valves, No. per Cyl. _____ o.d. _____ in., Port Diam. _____ in., Lift _____ in., Seat Angle _____ deg.

(17) Weight of Valve Reciprocating Parts, Inlet _____ lb., Exhaust _____ lb.

(18) Valve-Spring Tension, Inlet Open _____ lb., Closed _____ lb., Exhaust Open _____ lb., Closed _____ lb.

(19) Valve-Timing, Inlet Valve Opens _____ deg. _____ Top Center, Closes _____ deg. after Lower Center

Exhaust Valve Opens _____ deg. before Lower Center, Closes _____ deg. _____ Top Center

(20) Flywheel, o.d. _____ in., Weight _____ lb. Moment of Inertia _____

(21) Weight of Engine _____ lb., Including _____

CARBURETION

(22) Carburetor, Name and Model _____ Nom. Size _____ in.

(23) Specifications (Size of Nozzles, etc.) _____

(24) How Heated _____

(25) General Principles of Operation _____

(26) Description of Intake Pipe _____

IGNITION

(27) Name and Type of System _____

(28) Type of Distributor _____ Firing Order _____

(29) Type of Breaker _____ Maximum Spark Advance _____ deg., Retard _____ deg.

(30) Spark-Plugs, Name and Type _____ Size _____ in.

(31) Location _____ Gap _____ in.

LUBRICATION SYSTEM

(32) Type and Description _____

See Notes Corresponding to Numbers Under "Rules and Directions"

II—Reproduction of Suggested Airplane-Engine Specification Sheet

diameters of different portions, and specify which, if any, parts are jacketed.

(27) In case of two systems, state which was used in test.

(29) State if spark is fixed, or if spark control is automatic or manual. Maximum spark advance and retard are to be given in degrees of crankshaft rotation.

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(30) Give material of insulation, number of sparking points on electrodes.

(31) In addition to exact location in combustion chamber, state whether vertical, horizontal or inclined, and whether plug extends into combustion chamber.

(32) Give the general type of lubrication system, as: "recirculating splash;" "force-feed and spray;" "complete force-feed." Then describe in detail action of system and course taken by oil. State oil pressures and type of pump used. State name and grade of oil used.

III—Suggested Form for Propeller Specifications

Manufacturer .....

Serial No.....Dwg. No.....

Blades, No. .....

Diameter .....ft.....in.

Material .....

Laminations, No. .....

Type (Continuous or Spliced).....

Sheath (Kind) .....

Weight .....lb.

Length .....in.

Method of Securing to Blade.....

Propeller Weight .....lb.

Hub Diameter.....in.; Distance between Flanges.....in.

Bolts, No.....Dia.....in.; Radius of Bolt Circle.....in.

Designed for.....hp. at.....r.p.m. and.....m.p.h.

Theoretical Thrust.....lb.

Theoretical Power Required.....hp.

Theoretical Efficiency.....per cent

Section Characteristics

Radius, in.....	12	18	24	30	36	42	48	59	60
Angle of Attack, deg..	.....	.....	.....	.....	.....	.....	.....	.....	.....
Pitch, in	.....	.....	.....	.....	.....	.....	.....	.....	.....
Aerofoil	.....	.....	.....	.....	.....	.....	.....	.....	.....
Chord Length, in.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

IV—Suggested Form for Recording Test Data

.....Test of Model.....Airplane No.....

Manufactured by .....

Test made for.....at.....o'clock

.....19.., on.....Field.....U. S. A.

Dimensions and Description

Length of Course, miles: circular.....straight.....

Total Weight of Airplane and Load on Test.....lb.

Useful load: men.....lb.; fuel.....lb.;

oil.....lb.; other weights.....lb.

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Engine

Manufacturer .....

Model.....Serial Nos.: Right.....Left.....

Propeller

Manufacturer .....

Dwg. No.....Serial Nos.: Right.....Left.....

Remarks .....

.....

Condition of Airplane over Course	Time, min.	Altitude, ft.	Air-Speed Indicator Readings, m.p.h.	R.p.m. of Engines		Angle of Attack, deg.
				Right	Left	
Standing	.....	.....	.....	.....	.....	.....
Flying with Wind	.....	.....	.....	.....	.....	.....
Flying against Wind	.....	.....	.....	.....	.....	.....
Flying across Wind	.....	.....	.....	.....	.....	.....
Landing ..	.....	.....	.....	.....	.....	.....
Climbing ..	1	.....	.....	.....	.....	.....
Climbing ..	2	.....	.....	.....	.....	.....
Climbing ..	3	.....	.....	.....	.....	.....
Climbing ..	4	.....	.....	.....	.....	.....
Climbing ..	5	.....	.....	.....	.....	.....
Climbing ..	6	.....	.....	.....	.....	.....
Climbing ..	7	.....	.....	.....	.....	.....
Climbing ..	8	.....	.....	.....	.....	.....
Climbing ..	9	.....	.....	.....	.....	.....
Climbing ..	10	.....	.....	.....	.....	.....
Climbing ..	.....	max	.....	.....	.....	.....

Get-Off

Time.....min. Distance.....ft.; against wind.....across wind..... Condition of Field.....

Weather Conditions

Sunny or Cloudy.....

Temperature .....deg. F.

Barometer .....in. Hg.

Height above Sea Level.....ft.

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Wind

Direction .....
Velocity .....m.p.h.
Steady or puffy.....
Uptrend .....

Witnesses

Signature of Official Observer.....
Signature of Pilot.....
NOTE: Baragram, photographs, etc., should be attached to this report.

DISCUSSION

CHAIRMAN SOUTHER:—Mr. Rooney has touched on a practical problem. The test procedure in the field is necessarily incomplete, and anything done in systematizing the work is surely a step in the right direction.

RUFUS B. JONES:—I heartily endorse any effort at standardization of airplane tests. At present there is not sufficiently close relation between the flying field and the factory. I do not, however, entirely agree with Mr. Rooney's statement that the first scientific carelessness occurs when the finished machine is tested out at the aviation ground.

I should place a great deal of blame on inaccuracy in actual manufacture rather than upon those who get the data and make the alterations. Part of this inaccuracy is due to a lack of interest and personal initiative in the manufacturing engineers themselves, owing often to the great demands of their own parts of construction. Secondly, the phenomenal growth of the airplane industry (fostered largely by the European war) and the speed with which production has been urged have stood in the way of developing a valuable precision in both manufacture and tests.

It seems that the best way to bridge the gap between construction and flying tests is to have a chief engineer thoroughly familiar with both of these departments. Successful performance prediction is assured only by the use of three requisites; theory, data from practice, and "good horse sense." By careful study theory can be mastered in a comparatively short time, but its value becomes greatest when combined with experiment.

Data taken from machines should be in *simple*, compact form, and should consist only of general characteristics essential to performance. To my mind, Mr. Rooney's suggested data sheet, while thorough and scientific, seems too detailed for the average field records. The sheet forms a working basis, which actual tests alone can justify or modify.

Government requirements should be broader and laid out more

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from practical data and less from calculation. Rigid performance specifications should not be embodied in contracts until some experimental work concerning the machines in question has been done. If more care and time were spent on the experimental machine and upon the drawing up of rigid performance specifications there would be less difficulty in producing successful and acceptable machines.

CAPT. H. W. HARMS:—We have had more or less trouble, particularly with the manufacturers, in carrying out the guarantees of performance, probably because their design and theoretical predictions were not quite as reliable as they had felt. An accurate field test would be desirable for the purpose of having accurate records of design and predictions of performance, so that the difference between the actual performance of the machine and the predicted performance should be more or less consistent. In the original design of the machine and prediction of performance that slight difference would always be considered.

C. M. MANLY:—I think that no one questions the necessity for a consistent method of procedure in our tests, just as much in the matter of testing of the airplane itself as in testing the engine. We have apparently just arrived at the point where there is some real object in getting comparative results. Only a small amount of real test work has been done heretofore. Very few specifications had had to be met. The main thing was to produce a machine that would fly. Until the last two or three years little cross-country flying has been done in this country, and little in the way of altitude work, outside of competitions.

The main thing now is to try Mr. Rooney's suggestions, see what has been put in that is not needed, or what has been left out that is needed and get some real constructive criticism based on actual tests in the field.

HOWARD HUNTINGTON:—If different machines are to be compared we must have some basis for determining what load is to be carried in the tests. The amount of the load to be carried is arranged for but it is not a definite amount, simply showing what load was carried on this particular test. It is hard to decide what load should be carried in any test, because different machines are designed for different purposes, but why not arrive at a standard of this sort; have the load to be carried that for which the machine is designed with a given amount of fuel, that is, fuel for a given number of hours, simply for the purpose of comparative tests. I would recommend that fuel be carried in all of these tests sufficient for a two or four-hour period if a standard of this sort is to be adopted. The load should amount to that which the machine is designed for, two passengers, four passengers, a military load, of so many pounds, or whatever it is intended for.

ENGINE CONDITIONS IN THE AIR

FERDINAND JEHLE:—Mr. Rooney said the experimental work in the field was more or less hit or miss. The statement applies to a

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great deal of laboratory work as well. The standard tests laid down for testing automobile engines should be modified before using them for airplane engines. The latter is used for a different purpose.

Heretofore tests of aviation engines have been made at open throttle practically all the time. The aviator is up in the air where the pressure is considerably less; therefore, I think the standard test should include tests at different atmospheric pressures. That is not a very difficult thing to do. At the laboratory of the Automobile Club of America we put every engine through a set of tests in which we varied the barometric pressure.

Such tests would be excellent for studying the performance of carbureters. We would find that some carbureters are more adapted than others for use in aviation engines, because the difference in barometric pressure does not make as much difference in engine performance in some carbureters as it does in others.

Another important set of tests would be to run the engine at different speeds, and vary the load at these different speeds, just as the load would if the engine were driving the propeller. An important measurement at these speeds would be the fuel economy.

We should have some more reliable data of what we want the engine to do after it is in the air. That is, let us have some recording instruments installed on the airplane. We know from the altitude what the barometric pressure is, but we may not know the pressure forcing the air into the carbureter. That may be operated so it scoops up the air or operates under less pressure.

We should have the actual record of power performance of the engine in flight. It seems to me that a transmission dynamometer could well be applied, inserted in the propeller-shaft; it is not heavy and can easily be converted into a recording instrument.

PROF. J. C. RILEY:—We can inclose the inlet to a carbureter or reduce the pressure at that point to about 9 lb. instead of 14.7 lb. absolute, the former pressure corresponding to about 10,000 or 11,000 ft. altitude. It is easy enough to throttle the carbureter inlet so as to reduce the pressure. It is a little more difficult to collect the exhaust gases from the machine and carry them away as fast as they are liberated. Some aviation engines have exhaust manifolds; others have short individual exhaust pipes for each cylinder; others have none, and the rotating cylinder engines discharge directly into the air.

I have tried to devise some arrangement by which the low-pressure condition and blast of air can be applied to the engine, duplicating as nearly as possible the conditions on the surface. I came to the conclusion that with most of the engines up there it is possible practically to take all the air from the carbureter through a single opening, and that opening can be walled in. With the water-cooled engines it will be possible to remove the gases at low pressure. But we must remember that what would apply to a water-cooled engine in the air

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does not apply to an air-cooled engine or engines of the rotating-cylinder type.

Something more than just simply the air blast on the engine must be considered. A pound of air at the surface of the ground occupies about 12¼ cu. ft., and a pound of air at 12,000 ft. altitude occupies about 17 cu. ft. of space. That air is blown along by the cylinders at varying rates. However, the removal of heat is dependent on the weight of air. In order to duplicate conditions in real service, with the engine in the air, a blast of air at low pressure conditions should be available.

Any device for testing engines of various forms will probably have to take the form of apparatus in which low temperature, low pressure and a blast can be maintained. The low temperature can be produced by artificial refrigeration in something similar to a refrigerating machine. It can be produced by taking air that is blown against the engine at low pressure and letting it expand from atmospheric pressure to that low pressure through what is equivalent to an air engine. The scheme would be something like this; a centrifugal air compressor would draw the blast by the engine at 9 lb. absolute, compress it to atmospheric pressure, and get it away. The compressor would be on one end of the shaft and on the other end of the shaft would be an air-operated engine; air from the atmosphere, at 14.7 lb. pressure, would pass through that machine and come out at 9 lb. at low temperature. The real difficulty is that it will come out at too low a temperature. It will come out at a temperature below zero, thus duplicating conditions in high altitudes. A snowstorm results, but perhaps we can work out something to overcome that. However, we can reproduce the condition of as much air as is required at the actual pressure required and at a low temperature.

E. A. SPERRY:—On some parts of the fighting line flying at an altitude of 15,000 ft. is suicide, and they have to go 20,000 ft. So that a pressure of 9 lb. absolute is a bit conservative. If we design a machine to take care of this, we must consider 7½ or 7 lb.

J. R. CAUTLEY:—An airplane engine is not working on a horizontal plane. Therefore in any block test it seems to me we should work out some method of testing the engine when placed at an angle.

PROF. J. C. RILEY:—What value would be placed on tests in which the engine is tipped to a diving angle and held in that position for a minute and a half? Is it too severe?

C. M. MANLY:—We make the tipping test for both diving and climbing angles on all types of engines; the U. S. Army and Navy and foreign purchasers demand a tipping test of that kind. We have not tested any engines upside down yet, but we probably will have a demand for such a test before very long.

CHAIRMAN SOUTHER:—With all these difficulties presenting themselves, shall we be obliged to draw inferences from ground tests followed by flight, and be satisfied with them? Many tests performed in

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engineering work are not made under absolute service conditions, and yet by the practical knowledge, coupled with the laboratory tests, we arrive at a satisfactory result.

FERDINAND JEHLE:—We might be satisfied for the time being with testing under as near actual conditions as we can produce. Take, for instance, testing a carbureter under less than atmospheric pressure: If we study carbureters alone for the time being, studying fuel economy and power, the absolute pressure that the exhaust is under is not of as great importance as is possibly the pressure of the incoming air. The exhaust pressure has not as much to do with the mixture as has the incoming air pressure. The cooling of the air would be of great importance of course when testing the air-cooled engine, especially when using the cooled air under the reduced pressure.

AEROLOGICAL DATA

PROF. W. R. BLAIR:—The paper states that we should have reliable data on the climate and soil of every section of the United States. I think such data are at hand. We will get the information for the use of inquirers, or tell them where they can get it.

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EVOLUTION OF AIRPLANE WING-TRUSSING

By F. W. Pawlowski
(Non-Member)

It is hard for an inventor or designer to break away from the forms, types or examples already existing in nature; the first efforts to build a flying machine were therefore attempts to imitate the flapping of birds' wings, just as there were attempts to build locomotives that moved on legs.

We know how the airplane was finally created. It is not a replica of a bird; it does not imitate the bird-motions in flight (except to a certain extent in gliding flight), but it still retains the essentials of a bird's wing, although modified and immovable.

The problem faced by our predecessors of building wings large enough for a man-carrying glider or airplane, was an extremely difficult one. They had to determine how the big wing surface was to be made of light weight and rigid at the same time and also how the members of the wing framing were to be arranged.

MONOPLANE WING-TRUSSING

The examples furnished by nature in the wings of insects, birds and bats, already adopted for the construction of the umbrella, imposed themselves so strongly upon the minds of inventors that it is no wonder we find their application in the early flying-machine, and even in Lilienthal's (1896) and Pilcher's (1899) gliders, Fig. 1, and Ader's airplane (1897).

The fact that Henson at the early date of 1842 adopted the Fink truss for his wing construction must be considered and recognized as extraordinary. High credit must be given his power of mind and constructive ability. The Henson wing construction contains all the essential elements of the modern airplane wing, such as front and rear spars, and main and secondary ribs. The reduction of the number of exposed wires as compared with the umbrella type was considerable, and it is really surprising that Lilienthal, Pilcher, and others did not adopt Henson's construction. Much later (1909) Levavasseur adopted it almost without change for his Antoinette monoplane (Fig. 2). (In this, as in most of the following figures, all the so-called lifting wires are shown by full lines and the so-called landing wires by dotted lines.)

Several other designers of recent date adopted Henson's construction also, as it has the advantage of keeping the wings rigid even after they are detached from the body.

Although, in the meantime, the biplane wing became more prominent, we will proceed with the evolution of the monoplane wing. In 1910 Blériot adopted the Pratt truss, already popular in biplane construction, for his monoplane, which was of considerable span (Fig. 3). He evidently resigned voluntarily the possibility of almost

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doubling the wing area without much increase of resistance to motion.

Just a slightly different construction has survived until the present time in the German Taube (Fig. 4).

The type of monoplane shown in Figs. 5 and 6 rapidly became the most popular on account of its simplicity of construction and ease of adjustment.

The use of four pairs of lifting and landing wires on each wing, as in Deperdussin's seaplane, seems to be an unnecessary introduction of too much structural resistance. Two pairs of wires (Fig. 6) are the best, and are sufficient even for large-span machines; one pair of wires is sufficient for small-span racing machines. An example is the Ponier machine, which competed so splendidly for the 1913 Gordon Bennett Cup.

In 1900, before any other machine had flown, this type of wing trussing was used by Kress for his flying-boat, which was of a triple-tandem monoplane type. The interesting thing about it is that Kress was not an engineer but a tailor.

The resistance of the wires is a considerable item in the total structural resistance, so that Blanc in France actually built (1913) a monoplane with cantilever wings (Fig. 7), a rather risky construction considering the wing area used.

BIPLANE WING-TRUSSING

The difficulty of building large wing surfaces was realized as far back as 1866 by Wenham in England. He built a sort of multiplane kite, while Stringfellow in 1868 produced a triplane model, which unfortunately did not fly. But in spite of the remarkable example of Stringfellow, such prominent mechanical engineers as Sir Hiram Maxim (1888) with his huge multiplane, and Lilienthal (1896) with one of his biplanes, could not produce a simple and statically clear structure to combine the planes of their machines. A bridge engineer was the first to do so, and it was Octave Chanute who put the bridge truss in the biplane. Of course, it could be the Pratt truss only. The idea was adopted immediately by all airplane builders. As few of them were closely familiar with the principles of frame structures, there was some abuse of the "struts and wires" so that many biplanes of the early part of the modern era of aviation resembled closely the wire entanglement for field fortifications; this is shown in Fig. 8, in which the dotted lines represent the diagonals that were ultimately omitted.

The type shown in Fig. 9 soon became standard and prevails at the present time, the number of panels on each side varying from two to four in various constructions. Panels of equal dimensions, Fig. 9, are justifiable for bridge trusses, but are not the best for airplane trusses. By varying the width of panels, as shown in Fig. 10, the structure can be made of lighter weight or for the same weight, stronger.

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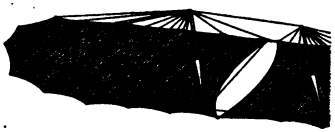

Fig. 1—Early Type of Glider

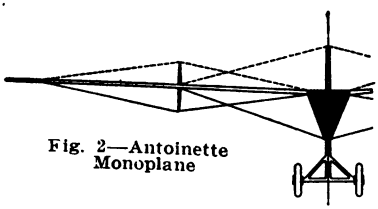

Fig. 2—Antoinette Monoplane

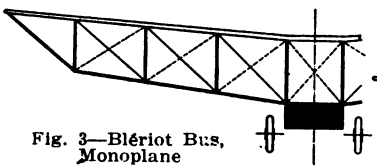

Fig. 3—Blériot Bus, Monoplane

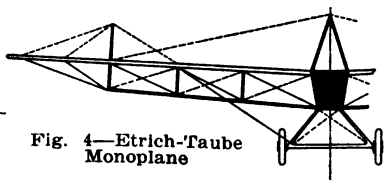

Fig. 4—Etrich-Taube Monoplane

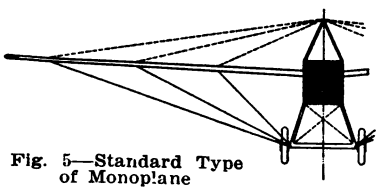

Fig. 5—Standard Type of Monoplane

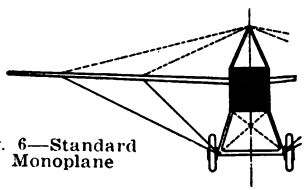

Fig. 6—Standard Monoplane

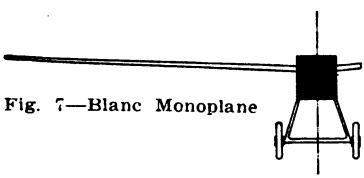

Fig. 7—Blanc Monoplane

Fig. 8—Early Type of Biplane

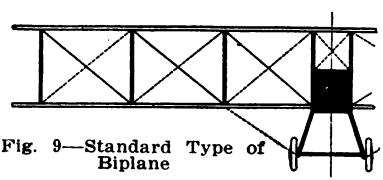

Fig. 9—Standard Type of Biplane

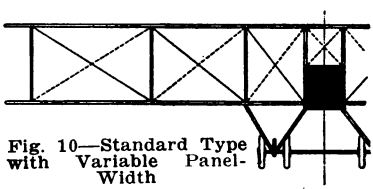

Fig. 10—Standard Type with Variable Panel-Width

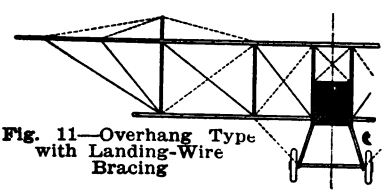

Fig. 11—Overhang Type with Landing-Wire Bracing

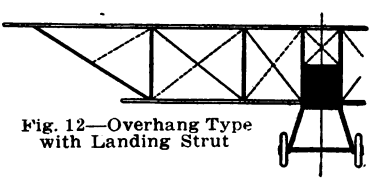

Fig. 12—Overhang Type with Landing Strut

FIGS. 1 TO 12—EXAMPLES OF MONOPLANE AND BIPLANE WING-TRUSSING

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The forces acting in the spars increase from wing tip toward the body; it is advisable therefore to decrease the bending or buckling length of the spar stations in that direction. Also, for the struts and wires the arrangement in Fig. 10 is more advantageous as the forces acting will be more uniform; that is, the extreme struts and wires are loaded more than those in Fig. 9. The members close to the body are loaded less, thus rendering the dimensions of these members more uniform. This advantage of the *variable-panel truss* is not yet fully appreciated, although the arrangement appeared in France five or six years ago.

Then came the *overhang-type biplane,* with its well-known mechanical and aerodynamical advantages. It was introduced by Henry Farman but had already been incorporated in the remarkable triplane model of Stringfellow. It is inconceivable, however, that Stringfellow had the same reasons for using overhang as had Farman.

The overhang has either *landing-wire bracing,* Fig. 11, or *landing strut,* Fig. 12, the latter arrangement being more advantageous as it offers less resistance to motion.

The resistance of struts and wires is a considerable part of the total structural resistance and the tendency to minimize the number of such members is therefore justified. An extreme example is one of the Bréguet airplanes, which had one panel 10.5 ft. long on each side of the body, in a machine of 40-ft. span, thus leaving about 8 ft. of free overhang on the upper wing (Fig. 13).

A more radical departure from the typical Pratt truss is displayed by the Henry Farman half-and-half monoplane and biplane machine (Fig. 14). The span of the upper wing is three times greater than that of the lower, so that the airplane is really a biplane (the central part) with two monoplane wings attached at the tips of the upper biplane wing. These machines are still in use in the present war.

The Ponier-Pagny biplane truss (Fig. 15) with equilateral triangles formed by struts and landing wires is a modification of the Pratt truss, as its essential members are the long diagonals of the rhomboidal panels.

Forms of Wireless Trusses

The real triangular bridge truss was introduced by the Albatross company in Germany about four years ago. The two examples shown in Figs. 16 and 17 are commonly known as wireless trusses.

The advantage is based on the considerable difference between the resistance coefficients of struts with stream-line sections and of wires or cables, the ratio or coefficient being about one to ten. As the thickness of struts is about ten times greater than the wire diameter, the elimination of landing wires by substituting for the lifting wires members that will transmit forces in compression as well as in tension offers interesting possibilities.

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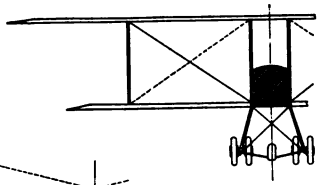

Fig. 13—Bréguet Biplane with Single Panel

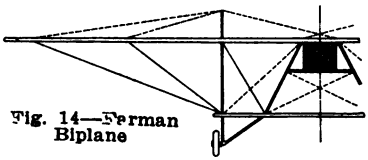

Fig. 14—Farman Biplane

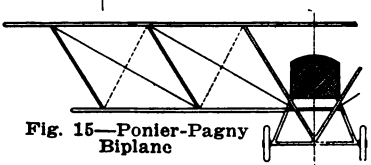

Fig. 15—Ponier-Pagny Biplane

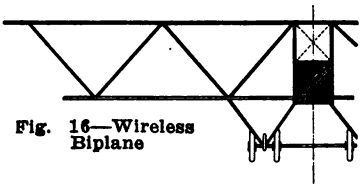

Fig. 16—Wireless Biplane

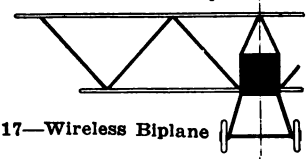

Fig. 17—Wireless Biplane

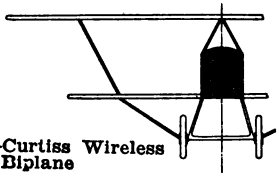

Fig. 18—Curtiss Wireless Biplane

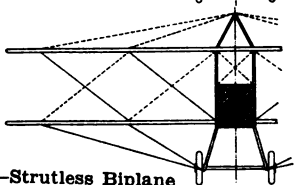

Fig. 19—Strutless Biplane

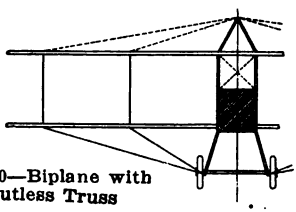

Fig. 20—Biplane with Strutless Truss

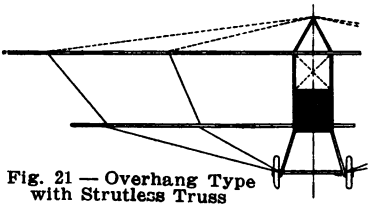

Fig. 21 — Overhang Type with Strutless Truss

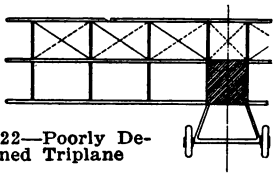

Fig. 22—Poorly Designed Triplane

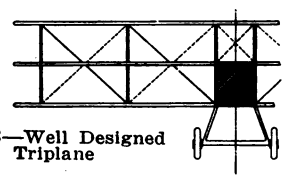

Fig. 23—Well Designed Triplane

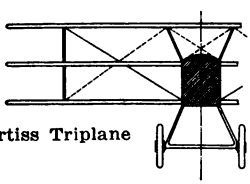

Fig. 24—Curtiss Triplane

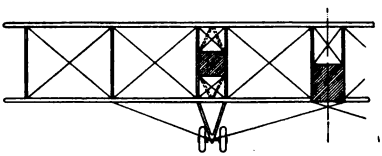

Fig. 25—Complicated Form of Biplane Truss

FIGS. 13 TO 25—EXAMPLES OF BIPLANE AND TRIPLANE WING TRUSSING

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As a matter of fact, the total length of all web members of a wireless truss can easily be made much less than one-half the total length of all wires and struts of the usual truss, so that the resistance of the web members can be reduced almost one-half with a small increase of weight.

With this construction it is difficult to connect the wooden struts to the sockets so as to transmit safely considerable forces in tension; it is also difficult to rectify the structure after it warps. When the wooden spars and struts are eliminated, turnbuckles and other adjusting devices are entirely unnecessary; also the difficulty of transmitting forces in tension is avoided; so it is curious that the wireless truss is not popular.

Just recently the Curtiss company has produced an interesting type of wireless truss (Fig. 18), in which the number and length of the exposed members are minimized. The construction is especially adapted to the fast small-span racing or scouting machines.

It is possible to imagine a *strutless truss* as a combination of two pairs of monoplane wings with the usual bracing (Fig. 19), but the total length of wires is considerable, so that the advantages of such a construction would be doubtful. Another form of strutless truss (Fig. 20) is much more promising and with the appearance on the market of wires having stream-line sections, it is possible that the structural resistance can be reduced even further than is the case with the wireless truss. Fig. 21 shows that this construction also can be well adapted for the overhang biplane.

EXAMPLES OF TRIPLANE TRUSSES

There were and there are few triplanes. The trusses can be treated here along the same principles as the biplane truss. I mention the triplane because in several instances the problem has been treated incorrectly, as shown in Fig. 22, in which the full height of the truss is not utilized, although it would increase the strength of the truss about four times. Figs. 23 and 24 show examples of correct treatment. The triplane has a mechanical advantage of decreasing the buckling length of struts by half, which makes them relatively several times stronger.

Fig. 25 shows a more complicated case of biplane truss for large high-power machines. The more uniform distribution of masses along the truss makes it lighter and stronger. (I omit entirely the question of dynamical stability involved in spreading out the masses in this case.) Here also different solutions are possible. In the Sikorski method the engines *M* are placed on top of the lower wing, close to the inner side of the struts. In the French method the engines are put between pairs of straight struts (see the full lines only). In the Curtiss method the engines are fixed between some special crooked struts (see the dotted lines). Each method has some small advantages and disadvantages, which can easily be seen from the figure.

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SIDE-BRACING OF AIRPLANES

Until now we have considered only the airplane wing-truss as viewed from the front, or the so-called *lift-truss*. Inside the wings, however, are placed the so-called *drift-trusses*.* Both the lift and the drift-trusses are combined to form a rigid three-dimension structure by means of bracing in planes passing through the struts and parallel to the plane of symmetry of the whole machine. This bracing is visible in the side-view of the airplane and I will call it *side-bracing*.

Side-Bracing of Monoplane Wings

Usually each monoplane wing has two parallel or slightly converging spars—the front and the rear spar. Each pair of spars, together with some central pylon or the landing chassis, taken as king post, form the front and the rear lift-trusses. Both are fixed in case of aileron control, or the front-truss is fixed and the rear one movable in case of warping. A monoplane has usually a *double lift-trussing;* the spars are at the same time members of both the lift and drift-trusses.

Fig. 26 shows the side-bracing of the Blériot monoplane-bus, on which the rear spar is braced to the lower girder of the *single lift-truss*. This arrangement is more advantageous than the one on the early type of Etrich-Taube (Fig. 27), because the separate lift and drift-truss (requiring three spars) is uneconomical from the mechanical point of view and the two wires offer about twice as much resistance as the single-strut brace in Blériot's construction. The recent type of Taube has side-bracing similar to that shown in Fig. 26.

Side-Bracing of Biplane Wings

The side-bracing of biplane wings offers many possibilities of design. The most common types, Figs. 28 and 29, are based on the same principle, but are adapted to the so-called straight and staggered biplane respectively.

The terms "lift-truss" and "drift-truss," although conventional, are not quite correct. None of the trusses takes care of lift or drift alone. Really, the resultant air-reaction upon the wings resolved into components parallel to the planes of the lift and drift-trusses gives the external forces acting on the trusses.

These components differ considerably from the drift and lift, not only in case of a staggered biplane, but also in a straight biplane, in which, for instance, at slow flight and large angle of incidence the forces acting on the drift-truss are frequently opposite in direction to the drift.

Figs. 30 and 31 show the *N-type* side-bracing, with which again

*The drift-truss, being enclosed by the wing, does not involve aerodynamical problems, and can be treated in any desirable way from the structural point of view only. A discussion of it is therefore omitted.

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the resistance of the wires of the ordinary bracing (Figs. 28 and 29) can be decreased by half. This bracing, especially when combined with the wireless lift-truss (Figs. 16 and 17), offers new and interesting possibilities for heavy large-span airplanes. It was applied by the Albatross company in the form of a triple lift-truss, which seems to be an unnecessary complication, as simpler combinations are possible.

Fig. 33 shows the *V-type* side-bracing, found in the modern Nieuport scouts. The two converging struts are fixed in a special socket fitted between the spars of the lower wing. This construction is also adaptable to straight biplanes (Fig. 32) but in both cases is especially good for an unequal-chord biplane. Although the trussing in the Nieuport machine is treated as of the double lift type, there is no reason why it could not be treated as a single lift-truss (preferably the rear one) with front struts acting as braces.

Development of Single Lift-Truss

The first single lift-truss was used in one of the first Chanute gliders, which was a quintuplane. Chanute, however, did not seem to appreciate the advantages of the single lift-truss system, as he adopted the double lift-truss for his subsequent machines.

It was Bréguet who (1909) produced and advocated the single lift-truss biplane, his main object, however, being to vary automatically the angle of incidence of the wings, which were hinged to the steel tubular spars (Fig. 34).

A more perfect and elegant construction of the single lift-truss, which can be called *I-type* side-bracing, or simply *I-strut*, was used in Dorner's flying boat (1913). The struts, Fig. 35, were fixed in sockets having long bases that reached from the front spar to the rear spar and were fixed to the spars. An almost identical construction was adopted in 1914 for the R. A. F. fast scouting machine. Mechanically, the front and rear parts of the socket bases can be considered as a cantilever subject to bending, accordingly as the center of pressure moves forward of or past the center of the strut. The struts are thus subject not only to compression but also to bending. The bending moments however in the average-size machine are comparatively small and can easily be taken care of by the sockets as well as by the struts. In the latter case it is the maximum moment of inertia of the strut-section that comes into play, and the fibers of material affected are almost idle, considering the buckling of the strut under axial load. Geometrically and aerodynamically the sockets can be treated as a well-filleted intersection of a strut of stream-line section with half of a stream-line body, thus offering little resistance to motion.

Advantages of Single Lift-Truss

The disadvantage of the single lift-truss as compared with the double lift-truss system is that it cannot well be adopted for stag-

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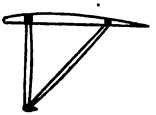


Fig. 26—Blériot Bracing

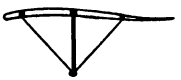
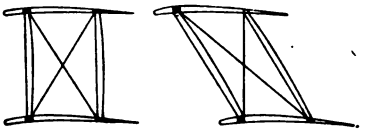
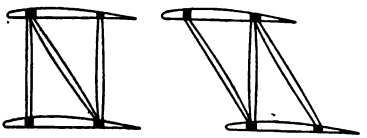


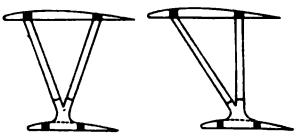
Fig. 27—Etrich-Taube Bracing



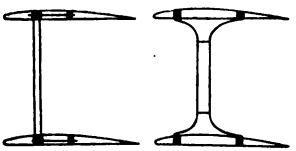
Figs. 28 and 29—Common Biplane Bracing



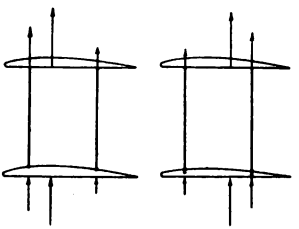
Figs. 32 and 33—V-Type Bracing



Figs. 30 and 31—N-Type Bracing



Figs. 34 and 35—Showing Single Lift-Truss



Figs. 36 and 37—Forces in Double Lift-Truss

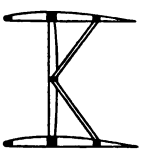


Fig. 38—Capt. Martin's K-Type Bracing

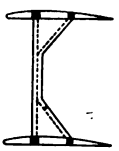
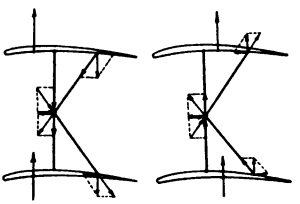
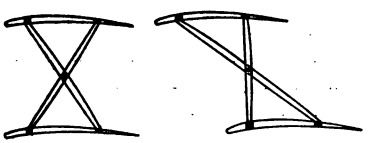


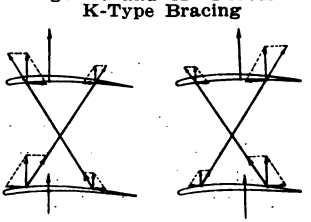
Fig. 39—Curtiss K-Type Lift-Truss Strut



Figs. 40 and 41—Forces in K-Type Bracing



Figs. 42 and 43—X-Type Side-Bracing



Figs. 44 and 45—Forces in X-Type Bracing

FIGS. 26 TO 45—EXAMPLES OF AND FORCES IN BIPLANE SIDE-BRACING

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gered biplanes, especially for those with a pronounced stagger. The advantages however are great and can be demonstrated as follows:

1. The strength of the struts varies as the moment of inertia of the strut section.

At a constant ratio of diameters of the strut section, the least moment of inertia varies as the fourth power of the thickness (small diameter) of the strut.

Therefore, the thickness of strut varies as the fourth root of the load that the strut can stand.

For the double load of a single lift-truss strut against the two struts of a double lift-truss, the increase of the thickness and therefore of the air-resistance will be only about

$$100\ (\sqrt[4]{2} - 1) = 20 \text{ per cent,}$$

or the air-resistance will be reduced by about

$$100\ \left(\frac{2 - \sqrt[4]{2}}{2}\right) = 40 \text{ per cent.}$$

The weights being proportional to the squares of the thickness, the gain in weight of struts of a single lift-truss against a double lift-truss will be about

$$100\ \left(\frac{2 - \sqrt{2}}{2}\right) = 30 \text{ per cent.}$$

2. The diameters of wires or cables vary as the square root of the load that the wire or cable can stand.

For the double load of one single lift-truss cable against two cables of the double lift-truss, the increase of diameter and therefore of the air-resistance will be about

$$100\ (\sqrt{2} - 1) = 40 \text{ per cent,}$$

or the air-resistance will be reduced by about

$$100\ \left(\frac{2 - \sqrt{2}}{2}\right) = 30 \text{ per cent.}$$

There is no gain in weight however in this case.

3. The larger-size wires and cables of a single lift-truss system allow a further gain in reduction of air resistance by using stream-line wires or cables. The latter are made of stream-line form by means of sharp specially-attached trailing edges, which might be impracticable on the small cables of the double lift-truss system.

4. In the double lift-truss system the forces acting on each truss depend upon the position of the center of pressure; at fast flight and a small angle of incidence, the rear truss carries a greater part of the total load—roughly speaking between two-thirds and three-fourths of the total (see Fig. 37). At slow flight and large angle of incidence the reverse is the case (Fig. 36). Thus considering the two extreme attitudes, each of the trusses is either partly idle or has an extra strength and therefore weight.

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In the single lift-truss the forces acting on the truss are almost independent of the center of pressure, as the reaction of the load at the root of the cantilever is equal to the load and independent of the bending arm.

Thus, the forces acting on a single lift-truss will be about 25 to 35 per cent smaller than the forces of which the front and rear trusses of the double system must take care in the worst cases. This will result in another considerable reduction of weight and air resistance.

Special Types of Side-Bracing

Fig. 38 shows a *K-type* side-bracing proposed by Captain Martin (*Scientific American*, 1911). It is another interesting type of the single lift-truss that has all the advantages mentioned. Besides, as can easily be seen from the action of forces in Figs. 40 and 41, the extra bending moments in the I-type strut due to the cantilevers (sockets) are eliminated entirely. This advantage however is strongly jeopardized by the extra weight and resistance of the braces.

The Curtiss single lift-truss strut (Fig. 39), which is used in the wireless-truss biplane and in the new triplane (as far as it can be understood from the published details) is built up of two steel tubes, one straight, the other bent in two places; both tubes being enclosed by a covering. The character of cover determines whether this strut should be considered either as of the Martin K-type, without the advantage of eliminating bending, or as a simple and cheaper type of the Dorner cantilever or I-strut type.

Finally the *X-type* side-bracing (Figs. 42 and 43) offers also certain advantages, especially as compared with the type generally used at present (Figs. 28 and 29) and even with the N-type (Figs. 30 and 31), as it belongs in the double lift-truss class.

The advantage over the N-type is that there is one strut less. The advantage over any other double lift-truss system is that the amount of load carried by each truss is practically independent of the variation of the center of pressure, although there is a certain increase of the forces due to the angularity of the struts. (See action of forces in the two extreme cases in Figs. 44 and 45.) The trusses therefore do not have as much extra strength as in all the cases of two parallel lift-trusses.

The gain in resistance and weight is evidently somewhat smaller than in the case of the I-strut, but in return the X-type side-bracing is adaptable to staggered biplanes and to large big-chord wings. The I-strut, and in general the single-truss, would offer too many constructive difficulties and risk in these cases.

NEW POSSIBILITIES IN BIPLANE CONSTRUCTION

Numerous interesting and entirely new possibilities in biplane construction can be obtained by combining the types of trusses and side-braces previously described. Some examples are:

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1. Wireless truss (Fig. 16, 17 or 18) combined with N-bracing (Fig. 30 or 31) can be treated as (*a*) double lift-truss system or (*b*) single lift-truss system. In case *b* remarkable results can be obtained by placing the front and rear bars of the *N*-type in vertical planes parallel to the plane of symmetry of the airplane.

2. Wireless truss combined with V-type bracing can also be treated as (*a*) double lift-truss system or (*b*) single lift-truss system.

3. Wireless truss combined with the I-struts—an almost ideal structure for small fast machines.

4. Wireless truss combined with the X-type bracing, giving a construction with the least number of members for big-span and big-chord machines.

5. Strutless truss (Fig. 20 or 21) combined with the X-type bracing, and so on . . . as I do not attempt to exhaust but merely to indicate the possibilities.

DISCUSSION

CHAIRMAN CHARLES M. MANLY:—One of the rather interesting things that we will soon take up is to try to arrive at some standard method, so that all of the various computations that are made may be comparable. We will not have one engineer computing stresses and saying that his factor of safety is ten, whereas by another's method of computation the factor of safety is eight or six or four. Professor Pawlowski's paper gives us a basis now in comparing different types.

O. E. STRAHLMANN:—The evolution of airplane wing trussing is a subject of growing importance to the aeronautical engineer. It was brought out in the paper that the Pratt form of truss was early taken up by practically all makers who have used it almost exclusively in the construction of multiplane machines. This form of trussing has proved fairly satisfactory in use, as an ample factor of safety can easily be obtained and high performance of machines has not been demanded. Experimenting is costly and as there was no real demand for airplanes in this country until recently, it is little to be wondered that new types of trussing were not brought out.

Aeronautics now however is growing at a tremendous rate. Even at present the performances demanded are difficult to attain, and these demands will ever be increasing, especially as regards military airplanes, where the utmost is required.

In general, speed range and rate of climb must be increased without seriously affecting the factor of safety. As these two much desired characteristics depend, among other things, upon the head resistance or drag, and upon the weight of the airplane, a form of wing trussing reducing both of these factors would be a step in advance.

Airplane wings are difficult to keep in alignment, owing chiefly

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to the stretch of the cables. The elimination of, or a reduction in, the number of cables with the necessary turnbuckles and soldered loops, by the use of some form of metal-tube truss would reduce the number of parts, simplify the assembly and give a structure that would keep its alignment. All these are of great importance, especially in the field.

It can hardly be expected that the same type of truss will be best suited for all types of airplanes from the small light pursuit airplane to the large and heavy bomber. The form of truss best suited for each type of airplane will have to be determined largely by experiment. Development along this line has begun in this country, a form of K-strut, the Farman type spoken of, and a form of Warren trussing having been used in recent constructions. The near future will undoubtedly see some of the constructions suggested by Professor Pawlowski developed and come into general use.

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PAPERS PRESENTED AT MEETINGS OF SECTIONS OF THE SOCIETY

CLEVELAND SECTION PAPERS

STEAM MOTOR-VEHICLES

By Abner Doble

(Detroit Section Associate)

The purpose of this paper is to present a summary of investigations covering a period of nine years. These were made to determine the possibility of overcoming certain serious objections and disadvantages under which the steam motor-vehicle formerly labored.

Ten years ago steam cars were in their zenith—not that a large number of makers were producing them, nor yet that the majority of cars were steamers, but rather that a most progressive and prosperous organization was producing these cars on a real quantity basis. The White steamer of that day was universally respected or beloved, accordingly as the person affected was a gas-car man or a steamer advocate.

The Stanley steam car has been manufactured since 1898 without cessation. The evolution of this car has been gradual and conservative, and it has enjoyed a well-merited reputation for service at low cost. A fire-tube boiler and locomotive-type engine have been used from the first. The Stanley Company has added improvements only when there was a well recognized demand. It has thus accumulated those necessities of modern automobiles, such as electric lights, stream-line bodies and one-man top. A condenser was adapted to the car in 1914, and as a result about 200 miles can be covered on one filling of the boiler. Kerosene is now burnt in the main burner (with gasoline for starting and for the pilot), and the mileage per gallon is high. The fusible plug has been abandoned in favor of a thermostat for shutting off the fuel in case the supply of water runs short.

A large number of more or less ineffective attempts have been made to produce a satisfactory steam-car by persons ill-informed on

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the actual requirements and apparently lacking in the necessary understanding of automobile-production conditions.

Immediately after the early-day popularity of the steam-car the internal-combustion engine began to be favored by engineers. With the introduction of the long-stroke high-speed engine in Europe the steam-car fell behind rapidly in the march of progress. I do not wish to convey the impression that motor-vehicle builders erred in selecting the gasoline engine. The market demanded cars and more cars, and the makers chose the only practical powerplant available. No one wanted a vehicle that emptied a horse-trough every 20 miles. Very few drivers were equal to the task of properly feeding the boiler. The idea of spending all the way from a quarter of an hour to an hour and a half in starting soon lost its relish.

LOW MILEAGE A DISADVANTAGE

One great disadvantage of the steam-car was the insufficient mileage that was obtained from the water that could be conveniently carried. Several steam-cars were equipped with an apparatus intended to condense the steam, but a continuous run of 100 miles without refilling was uncommon. Owing to the use of heavy cylinder-oil these condensers as well as the water tank required periodical cleaning. Steam cars not so equipped would run approximately 30 to 35 miles on a tank-full, about 35 to 40 gals.

Apparently no one had considered using a honeycomb radiator. The reasons advanced against it were that the thick oil was liable to clog the extremely small passages, and that the exhaust steam (particularly in cars with flash boilers) was liable to melt the solder. It was also believed that oil would injure the boiler, cause violent foaming and that the successful lubrication of a steam engine required a heavy molasses-like oil. It was particularly hard to reconcile these beliefs, and we determined that the best thing to do was to put a honeycomb radiator on a car and operate it with a fire-tube boiler. This we succeeded in doing late in 1913, and obtained several startling results. The car would run anywhere from 1000 to 1500 miles on one tank (24 gal.) of water. The boiler operation was entirely unaffected by the oil pumped into it from the engine cylinder. Having shown that it was possible to travel an adequate distance on one supply of water, we turned to the study of the steam-generator, with special regard to its operation when fed with water containing oil, graphite, and in winter alcohol.

The so-called flash boiler, consisting of a series of coils forming, in effect, one continuous tube, was naturally out of the question. Its entire absence of steaming stability was a source of constant aggravation to a driver in a hilly country. However, it had the immense advantage that the direction of the water-flow was opposite to the flow of the gases of combustion, which allowed the water to take the last possible heat unit from the flue gases. Its all-steel construction

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with consequent immunity from leaks due to low water was also a great advantage.

The vertical fire-tube boiler was also out of the question for production on account of its great weight, potential danger present with a large diameter shell, its high cost because of the apparent necessity of winding the shell with a mile of piano wire and its liability to leaks both from oil working through the expanded joints where the tubes were fastened into the heads and from overheating with low water. Notwithstanding these formidable disadvantages, when in good condition it was the best boiler from the driver's standpoint, owing to its large reserve of water heated to the steam temperature, which admitted of great acceleration. It was also efficient because of the surface-heating arrangement with extremely short distance through which the gases radiated heat to the tubes.

The water-tube boiler, which has been built in almost every conceivable shape for motor-vehicle service, seemed to offer a basis on which the good characteristics of the flash and water-level types of boilers might be combined. This at first seemed a forlorn hope, as the apparently conflicting conditions seemed unreconcilable.

Deposits of scale occur in every type of boiler, with a resultant drop in efficiency and added liability of burning the already extremely hot heating-surface. In the water-level types this scale would settle in the non-circulating portions of the boiler, such as the water-column and blow-off connections.

STEAM-GENERATOR REQUIREMENTS

In studying these apparent conflicts, we could see that all functions were closely related. That is, a water-level boiler held the temperature of the steam practically constant, with no possibility of temperatures high enough to effect a deleterious change in the lubricating oil. This allowed the same oil to be used over and over. It also allowed the use of a soldered radiator to condense the exhaust steam. The honeycomb radiator condenses such a large portion of the exhaust steam, that little make-up water is required, with the result that much less scale is introduced into the system. Since little water is lost, in winter alcohol can readily be used in large enough proportions to prevent freezing. The use of a mixture of alcohol and water results in an imperceptible drop in power because of the large amount of heat-carrying medium that must be circulated.

The use of regular gasoline-engine cylinder-oil for the lubrication of those parts in contact with the steam, would make a steam generating and condensing system of this kind practical. Such oil is more agreeable to handle and easier to procure than the heavy oil used in steam engines. It rapidly forms an emulsion with the water, owing to the violent agitation and intimate contact. It cannot form clots and clog up the radiator passages, and since the return from the radiator is introduced into the bottom of the water-tank the agitation of the

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contents of the tank is sufficient to maintain the emulsion. This insures that the oil is regularly pumped into the boiler along with the water. The oil that thus finds its way into the boiler performs several valuable functions: First, it coats thoroughly every portion of the interior of the boiler with an exceedingly thin film of oil. While this is thin at ordinary temperatures, it is much thinner at 485 deg. F., which is the approximate temperature of the boiler at 600 lb. pressure.

Scale will not stick to a surface coated with oil, so that the interior of the boiler is absolutely protected from scale as well as from rust. Very little scale-bearing water is introduced into the system

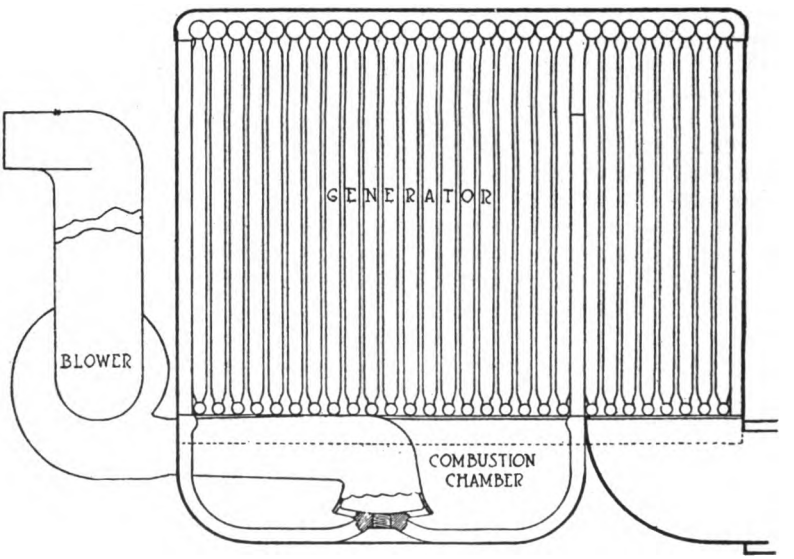

FIG. 1—NEW TYPE OF STEAM GENERATOR

because of the efficient condenser, but in several years' operation enough scale would be formed to render a boiler useless, even though none of it adhered to the tubes. The second function of the oil in the water is to combat this condition, which it does with thoroughness and dispatch. As soon as a particle of scale is thrown out of solution it is thoroughly coated with oil, which renders it incapable of sticking to any other particle. This scale therefore remains in suspension, and owing to the violent ebullition and constant flow toward the steam outlet is carried along and out with the steam, finally reaching the water-tank. This action appears to be exceedingly thorough, and in several years' use no accumulation of scale can be detected in any portion of the boiler. It appears that the scale problem can be solved when such particles of foreign matter are kept small enough so that they will be readily carried over with the steam.

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The steam generator, Fig. 1, which has been worked out to fulfill these inter-related conditions, is a flash-generator in theory, yet has the appearance of a water-tube boiler and has a water-level in the evaporating zone. The close and regular heating-surfaces give heat-transfer conditions resembling those of a fire-tube boiler, and yet the progressive water-flow, counter to the flow of the gases, with no circulatory flow, is characteristic of the flash type. The water enters the bottom of an economizer-zone and flows to the top under the action of the pumps and gravity; the hottest water collects at the top. From there the water overflows through a connecting pipe into an evaporating zone, where it is converted into steam. The water-level is maintained about half-way up the generator by an automatic by-pass valve; this is so arranged that when the regulator tube is filled with steam the by-pass valve is closed by the expansion of the tube, forcing the water from the pumps to lift the check-valve. The water can then enter the generator. As the water-level rises, the regulator tube is filled with water from an exposed pipe leading from the water manifold. This water is not in circulation in the generator, and therefore remains quite cool. The regulator tube then contracts and opens the by-pass valve, allowing the water to return to the tank.

The generator tubes are vertical, swaged at the ends to half their diameter, and welded into horizontal headers, top and bottom. Each section thus formed is connected to manifolds, top and bottom, for the exit of steam and the entrance of water. This construction is absolutely without danger of explosion and is also cheap to manufacture. Any damaged section can be replaced, or isolated pending replacement, in a few minutes. The casing of this generator consists of a ½-in. asbestos board, ¼ in. of mineral wool and a planished-iron jacket.

STARTING STEAM CARS

Perhaps the greatest disadvantage in operating steam-cars was that known as "firing-up," or getting the burner started to raise steam. Steam-cars almost without exception have used a Bunsen burner of the vaporizing type, which required pre-heating to vaporize the fuel. This was necessary to insure that enough mixture passed into the combustion space to ignite readily and to continue burning. After combustion was well under way the fire kept the vaporizer heated. When standing, a supplementary burner was lighted to maintain the vaporizer heat; this ignited the main burner when the car was to be used again.

About three years ago we first tried to eliminate the time and labor required to start combustion. It was suggested that a carbureter and spark-plug be used—a blower driven by an electric motor to furnish the requisite air, the idea being to use these with a regular Bunsen burner. This was found to work fairly well with gasoline, except that undesirable precipitation of the fuel took place. It also

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seemed necessary to provide means by which kerosene could be used for starting, without recourse to gasoline.

We finally discovered that kerosene could be ignited by an electric-spark with absolute certainty and regularity, if these conditions are observed: First, the kerosene must be separated mechanically so that the individual particles are sufficiently small to insure a rise in temperature past the point of ignition during the time in which

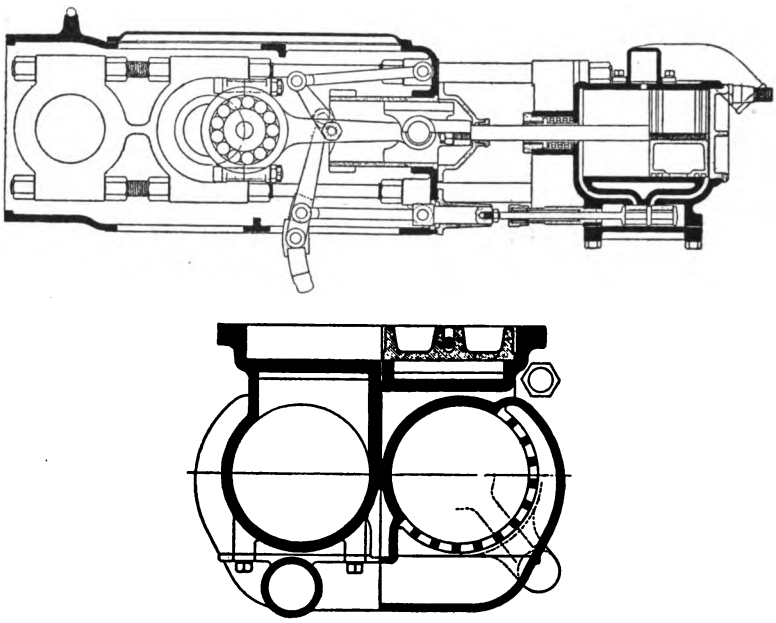

FIG. 2—SINGLE-EXPANSION UNIFLOW ENGINE

they absorb heat from the spark; second, the spark must occur near the atomizing nozzle at which point the fog is so dense that one group of kerosene particles igniting invariably ignite the rest. Third, the velocity must be so low that the particles can absorb sufficient heat from the spark to exceed the ignition temperature. Fourth, the mixture must be much richer at the point where ignition is to occur than is that for most efficient combustion. The combustion should occur in a refractory chamber so arranged that it attains an extremely high temperature; complete combustion of a large amount of fuel can then be obtained in a small space.

Thus in a complete apparatus, we have an electric motor, direct-connected to a multivane blower, and a graduated kerosene pump. The kerosene pump draws a measured quantity of fuel from the sup-

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ply tank and forces it through the atomizing nozzle; the resultant fog is ignited by a spark-plug. A measured amount of air is forced in by the multivane blower, which whirls the rich ignited mixture down through an inlet tube against the bottom of the refractory combustion chamber, where the fuel is consumed. To stop the combustion it is only necessary to break the blower-motor circuit. This is done automatically by a regulator set to operate at a pre-determined steam pressure.

With the old-fashioned Bunsen burner, which has been used on all previous steam-cars, it is necessary first to heat the vaporizer. This

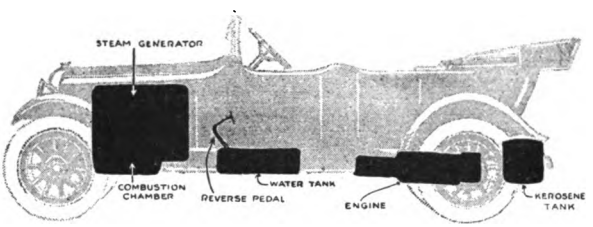

FIG. 3—STEAM CAR SHOWING LOCATION OF PRINCIPAL PARTS

is done with a drip-cup or a painter's blow torch, although on modern steam-cars acetylene gas is used. The fuel valve is then opened slightly, allowing very little fuel to flow until the burner has become well heated, after which the fuel valve can be left open. The starting of the fire takes about six minutes and requires the care of the operator until it is going well. After the fire is started, steam is made quickly. On some types of boilers enough pressure can be raised to start the car in about a minute and a half after the fire is under way. It is therefore apparent that if practically the entire time formerly used in starting the fire can be saved it is a reasonably simple matter to build a powerplant that can be started in a short time, with no labor or attention required.

The engine of a steam vehicle should last for many years of hard service. It has proved to be a relatively simple matter to provide ample dimensions of the working parts so that the mechanism is safe for continued operation under maximum conditions of load. In order to have efficient working it is necessary to provide for high expansion. This can be obtained with a compound engine, but not satisfactorily, as the ratio of cylinder volumes has to be carefully determined in relation to the probable loads, speeds and steam-chest pressures. These conditions vary so widely that the single expansion engine, Fig. 2, is necessary.

To provide the high expansion desirable, with a simple noiseless valve gear and one valve per cylinder, it is imperative to use the uniflow principle. In the uniflow engine the valve takes care of the steam

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inlet only, the exhaust passing out through ports at the end of the stroke when these are uncovered by the piston. It is thus possible to secure cut-off at 5 per cent of the stroke. Since the thermal conditions in the uniflow cylinder are practically ideal, it is unnecessary to use superheated steam. This means that little cylinder lubrication is required, and the troubles formerly caused by superheated steam are absent.

The engine directly geared to the axle, with a 47 to 48 ratio, can produce enough torque to slip the driving wheels on dry ground. The slow engine speed thus possible makes elaborate lubrication systems superfluous. The general arrangement of the principle parts of a steam-car is shown in Fig. 3.

ADVANTAGES OF A PERFECTED STEAM POWERPLANT

1. Torque range of 100 per cent with a maximum torque available at zero speed; change-gear mechanisms and clutch therefore unnecessary. Mean effective pressure (and equivalent drawbar pull) always under control of the operator; variable by throttle from zero to maximum, a maximum limited only by the resistance between the driving wheels and road.
2. Utmost mechanical simplicity, with not over twenty-five moving parts in the entire car, and only fifteen in the engine.
3. Smooth and quiet operation, owing to low engine speed and to location of engine on axle.
4. Low running cost; kerosene or crude oil used for fuel.
5. Low manufacturing cost owing to simplicity of construction and lack of fussy work in production.
6. Entire absence of lubrication troubles; no contamination of crankcase oil by kerosene, gasoline, water, road-dust and carbon.

DISCUSSION

E. G. THOMAS:—Mr. Doble has contended that multicylinder engines are unnecessary because if steam is used a two-cylinder engine is sufficient. I have ridden in his car at speeds varying from 1 to 60 m.p.h. It was a most pleasing sensation. There was absolutely no noise. The car attained any speed desired at any time.

MR. UTICH:—What does the seven-passenger car weigh?

ABNER DOBLE:—A seven-passenger car of 128-in. wheelbase, 56-in. tread front, 57-in. tread rear, equipped with a rather heavy body and 33 by 5-in. wheels weighs 3100 lb., with tank filled ready for the road.

CHAIRMAN ARTHUR J. SCAIFE:—What is the greatest horsepower obtainable with this type of powerplant?

ABNER DOBLE:—The highest normal horsepower that we have used so far is 25, but a 25-hp. steam powerplant at the standard pressure of 600 lb. per sq. in., will exert about 132 hp. for about eight minutes.

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S. L. BLACKBURN:—What is the maximum pressure that the boiler will stand?

ABNER DOBLE:—The boiler is designed for a working pressure of 600 lb. The safety valve is set for 1000 lb. The boilers are all tested to 5000 lb. They will rupture at about 8500 to 9000 lb. At this pressure the tubing ruptures at a place remote from the welds. My own car has been in service since December, 1913. The safety valve has never blown. This means that the maximum pressure has never reached 1000 lb.

THERMAL EFFICIENCY

WALTER C. BAKER:—Why is an efficiency twice that of a gasoline car claimed?

ABNER DOBLE:—Everything depends upon what you mean by "efficiency." We know that 18 per cent thermal efficiency is obtainable from a gasoline engine running at full load. We also know that cars do not run at full rated load much more than 1 per cent of the time. When running at 20 or 25 m.p.h. about 5 hp. is required to drive the car. Under such light load the ordinary engine will have a thermal efficiency of from 4.5 to 5.0 per cent. The highest thermal efficiency we know of to-day with the steam powerplant is about 21.8 per cent at its full rated load. This is obtained by using a combustion system in which the air is preheated, at the risk of burning out the grate bars. The Doble steam generator has no grate bars, but uses a refractory material that we developed. It will stand about 3400 deg. F. before it fuses. The temperature attained in our fire box is about 2600 deg. F. The air is preheated to 200 deg. before it enters the carbureter, by utilizing about one-third the heat that would otherwise go out of the stack. The boiler efficiency without the economizer is about 82 per cent. This is equivalent to standard practice in boilers. With our boiler we can increase the efficiency about 4 per cent by the economizer and by using a regenerator, which can be placed on the end of the stack, we can raise the boiler efficiency to about 92 per cent. The best net thermal efficiency that we have been able to secure from our powerplant is about 16 per cent under full load. With the 5-hp. load imposed when a car is driven at 25 m.p.h., we realize 14 per cent net thermal efficiency. My car, which was built three years ago and is crude in some ways, has been driven almost 40,000 miles. It will run 15 miles to the gallon of kerosene under favorable conditions and will average about 11.5 miles per gallon although I drive through traffic and mud a part of the time. The old type of steam car never ran more than 7 miles per gallon.

H. H. NEWSOM:—What piston speed is used in the engine?

ABNER DOBLE:—We have found that the most efficient piston speed is 375 ft. per min., which corresponds to a car speed of about 37 m.p.h. I have driven my car at 80 m.p.h. The corresponding piston speed is 800 ft. per min., not counting the slip, which would be about 12 per

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cent at that point, making a maximum piston speed of about 900 ft. per min. I have never run an engine at any higher speed than that in a car.

H. H. NEWSOM:—What is the temperature of the steam?

ABNER DOBLE:—The theoretical temperature of saturated steam corresponding to a pressure of 600 lb. is 490 deg. F., but we find sometimes that on ordinary loads, there will be 100 deg. superheat in excess of that. Under full loads it will be down to 490 deg. F. owing to the fact that we will then probably have 3 to 5 per cent of moisture in the steam.

TYPE OF COMBUSTION SYSTEM

MR. WAITE:—What sort of a combustion system is used?

ABNER DOBLE:—An efficient blower furnishes the requisite amount of air, and mixes with it enough kerosene to make a very rich vapor. The kerosene is atomized and the vapor ignited by an electric spark before the air required for complete combustion is added. The spark-plug is connected in parallel with the blower-motor circuit. The ignited mixture flows through the inlet tube and into the combustion chamber, where it burns completely before the hot products of combustion pass through the boiler.

MR. SCHWARTZENBERG:—What about the fire hazard?

ABNER DOBLE:—It is negligible with kerosene as fuel.

WALTER C. BAKER:—Is the exhaust clean when using kerosene?

ABNER DOBLE:—Yes. All carbon is consumed at 1800 deg. F. The combustion-chamber temperature under normal working conditions is about 2450 deg. The feed is set so that the fuel is entirely consumed. The exhaust will smoke sometimes in starting until a temperature of 1800 deg. F. is reached in the combustion chamber.

MR. SCHWARTZENBERG:—Is the heat objectionable when driving in summer weather?

ABNER DOBLE:—The generator is insulated with a special material that does not reach a temperature of much over 150 deg. F. We use a dashboard that comes down to the frame, and then the frame is covered with a floor. A space of 2 in. is allowed between that floor and the floor-boards proper. We use a 1-in. cocoa mat on top of the floor-boards. The result is a much cooler car than one of the regular gasoline type.

CHAIRMAN ARTHUR J. SCAIFE:—How flexible is the powerplant? If the throttle is opened or closed suddenly what is the variation in pressure?

ABNER DOBLE:—If the throttle valve is suddenly opened wide with the car at a standstill, the pressure will drop from 600 to 450 lb. by the time the car reaches a speed of 60 m.p.h.

WALTER C. BAKER:—How many seconds does it take to accelerate to 30 m.p.h.?

ABNER DOBLE:—Five and one-half seconds from a standstill to 30 m.p.h.

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E. L. CLARK:—Fig. 3 shows the engine built right onto the back axle. What is the unsprung weight?

ABNER DOBLE:—The unsprung weight added to the axle on the older car was 100 lb. The new engine will add about 10 lb. more, but we have saved about 15 lb. in the differential, as we use no differential cage. The piston, piston-rod and cross-head weigh about 8 lb. on each side of the engine. The latter runs at 600 r.p.m. when the car is traveling 60 m.p.h.

Over 200 steam-driven omnibuses have been running for a long time in England. Last year they changed the fuel from kerosene to coke. The latter is fed by automatic stokers driven from the engine. The grate rocks so many times a mile, and all the driver has to do is shovel in a little more coke every 10 miles or so. Coke sufficient for about 50 miles is carried. They also use coke-burning steam lorries.

A. M. DEAN:—What is the temperature of the engine when running at 25 or 30 m.p.h.?

ABNER DOBLE:—The steam temperature at the intake when running at 25 m.p.h. is just about 390 deg. F. The temperature at the exhaust, in every case, is 212 deg. F., or within 2 or 3 deg. of that, because at the exhaust the steam contains about 15 per cent water.

S. L. BLACKBURN:—What is the piston displacement of the engine?

ABNER DOBLE:—It is 314 cu. in. per revolution.

MR. DUNKIN:—What is the bore and stroke of the engine?

ABNER DOBLE:—It has a 5-in. bore and 4-in. stroke.

REVERSING ENGINE

E. L. CLARK:—How is the engine reversed?

ABNER DOBLE:—The "Joy" valve gear used was invented a long time ago by David Joy in England. It is the same gear that the White company used on its engines. The engine is reversed simply by changing the timing of the valve; that is accomplished by tipping the rock shaft to an inclination opposite to that used in running forward.

H. H. NEWSOM:—Does the Joy valve gear have a link motion?

ABNER DOBLE:—No, it does not. It is called a radial valve-gear, and is driven from the connecting-rod, as shown in Fig. 2. The end of the anchor link is nearly horizontal. The valve link is attached to what we call the "correcting" link, because without it the valve would not have a correct motion.

H. H. NEWSOM:—Is the control manually operated?

ABNER DOBLE:—The control is by a pedal.

H. H. NEWSOM:—Is it advanced as the speed increases?

ABNER DOBLE:—No; to start the car the pedal is moved to the first notch. That gives cut-off at three-quarter stroke. At higher speed, fuel can be saved by moving the pedal to the next notch.

W. D. APPEL:—What is the maximum cut-off when the valve gear is in the extreme position?

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ABNER DOBLE:—The maximum cut-off is 2½ in. on a 4-in. stroke. There are two other positions; the first for ordinary running and for extreme acceleration is at one-quarter stroke, and the second for economical running, or for extremely high speed after acceleration is at one-eighth stroke.

W. D. APPEL:—With the cut-off set at one-eighth stroke, would it be possible for the engine to stop on dead center so that it could not be readily started?

ABNER DOBLE:—Unless the cut-off is later than mid-stroke this can occur. In order to start under this condition it is necessary to use the reverse pedal first.

PRODUCTION COSTS

MR. SCHWARTZENBERG:—With a properly equipped plant, turning out three hundred cars a day, and with metal at normal prices, what would be the cost of manufacture as compared to a $2,000 gas car?

ABNER DOBLE:—A car to give the same power performance as a Cadillac, for example, and with the same finish and quality of workmanship, will cost $198 less per car. In general the saving will amount to 8 or 10 per cent of the list price of the car.

S. L. BLACKBURN:—Can the car be built in any class? Say for example in the $700 class?

ABNER DOBLE:—Yes. But the performance will be better and less care is necessary in finishing and fitting pistons and cylinders.

C. E. WILSON:—Are the braking possibilities the same as in gasoline cars.

ABNER DOBLE:—Yes; by using the reverse pedal it is possible to stop almost instantly. Beside this two sets of brakes are provided as required by law. The center of gravity of the car is low and nearer the rear than in gasoline cars, hence the car holds the road better and the wheels do not slide so much as they would otherwise.

CHAIRMAN ARTHUR J. SCAIFE:—How is the engine lubricated?

ABNER DOBLE:—By the time the steam enters the cylinders, it contains about 3 per cent moisture, which increases to about 8 per cent as the expansion takes place. This moisture does the lubricating. Little internal lubrication is required, for the piston speed is low at ordinary driving speeds. The cylinder surface is cast iron, which is easy to lubricate. We use oil to prevent corrosion and to help lubrication. The last gallon of oil I used in my car was sufficient for 12,200 miles' operation. The oil used is primarily to clean the scale from the boiler.

GEORGE W. SMITH, JR.:—What is the weight of the powerplant?

ABNER DOBLE:—The new engine will weigh about 240 lb. The old engine weighed 220 lb. The generator will weigh about 520 lb.; the water tank about 250 lb. The radiator will weigh 15 lb. more than a gasoline-car radiator. The engine will develop 70 hp. continuously.

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THE GAP BETWEEN COMMERCIAL MEN AND ENGINEERS

By Chas. W. Mears
(Non-Member)

Everybody who has had relations with engineers as well as with commercial men knows that important differences in mind and conduct characterize these two classes. They appear to differ in what they think and in their method of thinking. They seem to differ in their attitudes toward men at large, and toward things. It is safe to say that engineers and commercial men are not instantly interchangeable; they are not like two castings from a single pattern. Neither does one class yearn to be like the other.

These differences are usually accepted as a matter of course, as a condition that exists whether we will or not, and, therefore, as a condition that nobody need bother much about. But even a little light on the subject would be better than total darkness, and it will not injure us to inquire *why* these differences exist. And since human nature, after all, is the most engrossing of subjects, perhaps we can find pleasure along with profit in diagnosing the case.

A reasonably safe assertion, to serve as a starting point, is that men trained in science as a rule think more logically than do men more directly occupied in commercial pursuits. This follows, undoubtedly, from the fact that science accepts nothing as trustworthy until it has been logically proved. The engineer acquires habits of mind and of action that harmonize with the instruction he has received. Since his own mind pursues logical, rational paths, the earnest engineer expects things to be done with logical consistency, and he also expects people to act reasonably. This, I believe, explains why so few scientific men are enthusiastic toward society or commerce. They discover to their disappointment that most people have no very profound conception of that logical method of thinking and acting which is the alphabet and foundation of science; and rather than suffer the annoyance and confusion of association with illogical thinkers, scientific men innumerable have practically shut themselves off from the world at large, mixing, if at all, in the most limited way socially, and in a restricted way commercially.

The engineer of an automobile plant displays no consuming desire to meet and mix with the public that buys the car he designs; it is hardship enough that he must meet and cooperate with commercial managers and boards of directors that seem to prosper despite their noncomformity to his logical standards. When a scientific man does show a fondness for the public, when he takes pleasure in reducing his knowledge to a "popular" level or delights in making speeches to the "hoi polloi," the suspicion readily gains ground that this ready

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mixer is only superficially scientific and, in reality and at bottom, is something of a mountebank.

To the scientist the thing that counts and the only thing that counts is the *work* the man can do; and if his work is good, the scientific man needs no other badge of honor, whereas if his work is not good, he is cast into outer darkness by his fellows, and no alibi is trumped up on his behalf.

When a young man goes to college and takes a classical course, nobody is surprised if he continues through life without finding a sure connecting link between the things the college taught him and the things that business requires him to perform. But when a young man takes a scientific course, he is not permitted to forget that he is then and there fitting himself for his life work. And what he studies becomes veritably a part of his personal being. Not that he becomes a creature of brass or steel, but that the principles he learns become a vital part of his action. And the more gladly does he become steeped in principles when he learns that principles alone endure. And he learns, too, if he have his wits about him, that the principles that are enduring are the principles governing THINGS, *inanimate* things. Upon this point I shall later dwell at length.

The soundness of science is based on the fact that it deals with things. Sociology does not yet rank with mechanics as a science, because sociology deals with human beings, and human beings have a disturbing faculty of slipping away from principles, of refusing to "stay put."

THINGS AND HUMAN BEINGS

Commerce deals, apparently, with things, but actually it deals with things only incidentally. Commerce exists for the purpose of making money. Now we cannot get money from things: we can get money only from people, in exchange for things. That is why commerce quickly shifts from one thing to another without compunction, from bicycles to automobiles, from pianos to phonographs, whenever greater profit is in sight. But one change commerce never makes, never has made, and never will make; commerce will never cease doing business with human beings. While the enduring elements in science *are things*, the enduring element in commerce is human beings. Commerce handles only such things as are desired by humanity. The real training for commerce is, therefore, a training in the essential phases of human thought and conduct, whereas the training for mechanical science is a training in the nature and conduct of some particular things.

Here, then, if I am not mistaken, is the gap, the gulf, between applied science on the one hand and commerce on the other; it is the difference between things and people. And it explains why scientific men have so little patience with human frailties, and why commercial men are so seldom scientific, why they so frequently perform actions not to be classed as logical or consistent.

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Astronomy is the most accurate of all sciences, and the reason for this undoubtedly is that its subject-matter is so far removed from actual human contact that its elements obey natural laws totally free from the interference or influence of the human astronomer.

Chemical laws seem sometimes to fail: an experiment may not turn out as it should have. But when the experiment is renewed and the operator exercises an increased degree of watchfulness, and he at last succeeds, then he knows that the law was right. It was the wrong proportions of the ingredients that caused the initial failure: the error was his own. This possibility of failure exists wherever man is able to influence subject-matter.

We have reason to believe that nature conforms regularly and thoroughly to certain laws. Where science is master, that fact is pretty well proved. If all men were perfectly natural, they too, would obey natural laws invariably and implicitly. But, unfortunately or otherwise, man is given a brain, and into that brain enter all sorts of impressions, setting up notions of greater or less strength; these notions in turn influence man's conduct. Not only does man become unnatural and unreliable because of what he thinks for himself, but also he departs from nature on many occasions because of what is told him by somebody else who may be a less accurate thinker.

The only absolutely logical thing in the world is matter, and matter is logical because it has no choice in itself. Given the power of choosing, matter would become as freakish and temperamental as human beings: water at one time would have an affinity for oil and at other times a repugnance toward it, and we might possibly have demonstrations of automobiles running around without the help of fuel.

And yet, though man varies the expressions of nature in consequence of his own thought, old Mother Nature never leaves him totally free to his vain imaginings. If she were to do so, he might imagine that he could live without food, and if enough men were to get that notion, the race would shortly become extinct. In many things nature does not seem to care whether man acts logically or illogically: probably logic is one of those playthings that she permits him to have for his amusement.

But she does insist that he perform certain functions, such as breathing, eating, exercising, and sleeping, and no man omits these functions except at the cost of his life. Therefore, it is not by taking thought that a man can stay awake endlessly, or cease permanently to breathe. He has little or no choice. Let his brain determine ever so positively to keep him awake, and finally the watchful brain itself becomes exhausted, and nature's flesh triumphs over this wonderful master of destiny known as brain power.

We seem now to be getting away from commerce and mechanics, but we shall presently get back. I have said that mechanical men are more logical than commercial men. I mean to show that the

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wisest commercial men are wise in that they understand more about human nature than about things, and hence we need to pursue human nature a little farther.

WHY COMMERCIAL MEN ARE WISE

The child plays ball for fun: at least he thinks he plays for fun, if he thinks anything at all about it. But nature impels him to play in order to do hard work for her in building muscles and breathing apparatus. Man eats to appease his hunger and satisfy his appetite, but hunger and appetite are only nature's lures in order to get food into man's stomach, to supply the body with fuel. Man sleeps because he is tired, and, while his brain is out of commission and unable to interfere with her processes, nature slips in and repairs the day's waste. Thus nature impels man to do her bidding, and not once does she appeal direct to his rational mind. So far as she is concerned, he could get along fairly well without any mind worth mentioning. She operates exclusively through his feelings, which are not logical in the mental sense, if they are logical in any sense whatever. And so we come to the conclusion, that man, as a human being, is a bundle of contradictions, a creature who thinks one thing and does another; a being, therefore, who is hard to decipher.

And yet, men who deal with other men must decipher them at any cost, for success in dealing with human beings depends largely upon that deciphering ability. Not only must man be deciphered, but one's commercial plans must be made to dovetail into human frailties. We cannot change humanity, and we cannot do business with human beings unless our commercial plans fit human needs and human notions. Therefore, the thing that must undergo change to suit conditions is the business method.

To make business conform to human fads, for instance, might be interpreted by strict intellects as decidedly illogical. We might be making a product that, according to the soundest reasoning, people ought to have and ought to want. But if people do not want it, if they refuse to exchange money for it, we must throw these logical conclusions out of the window, or, instead of that, pass through the bankruptcy court.

EXPEDIENCY STRONG ELEMENT

We come now to an element of commerce that is powerful, even though at times it may be illogical. I refer to expediency. Expediency pertains to utility or advantage rather than to principles. In business there are things that are logical, reasonable, rational, lawful to do, but that still cannot be done profitably; and let us not forget that business exists for the purpose of making profit. At the present stage of the automobile industry, it would be the greatest of hardihood to market a car having a two-cylinder gasoline engine. It would be legal to make a two-cylinder gasoline car, and it might be logical and reasonable to do so. But expediency says, "Don't do it,"

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because the whimsical human beings who buy automobiles cannot be induced at this hour to look at less than four cylinders.

Commerce must meet the needs and wants and whims and fads of human beings. Also human beings are illogical. It is imperative therefore that commerce adapt itself to illogical situations. When it does so, and cannot defend itself logically, the action is explained as one of expediency. And expediency generally has the right of way in business conduct.

I recall the time when the last big producer abandoned steam and embraced gasoline as a motive power. Without knowing a single inside fact in the case, I have no doubt whatever that the change was altogether one of expediency. The big moving factor in the decision against steam was not its disadvantages. As the manufacturer in question looked about him, he saw that the big public demand was for gasoline cars; he decided that it was easier to keep a great factory busy producing gasoline cars than to keep up practically a single-handed fight for the steam vehicle. That step was not, I take it, a confession of the utter impossibility of overcoming steam-car disadvantages. Rather it was a recognition of the easiest way to commercial profit. I can imagine that the engineering staff would have voted to continue, and not to throw away the specialized experience of years. To stick to the steam-driven car and to bring it nearer perfection would have been the logical, the consistent thing to do.

It was commercial expediency that eliminated the steam car from competitive markets, and steam, so far as the public knows, has been dormant ever since. Whether, in the industry's mad hunt for novelties, commercial expediency will again embrace the steam car remains to be seen. The logical thing for plants equipped to make gasoline cars—providing the sale of the product is successful—is to continue to make gasoline cars. So, to say the least, we shall now witness a contest between logic and expediency. I think I can predict which will win.

In general, we are forced to confess that it is extremely difficult to get men to do the logical thing in the same sense that we can get chemical compositions to do the logical thing. Such laws of mind as have been promulgated are not offered as absolute. Heredity, environment, habits of thought and conduct, a thousand incidental influences affect man and he is not at all unlikely at any time to do the unexpected and the surprising. Psychologists and sociologists are not hopeless that mind and conduct can be reduced to dependable principles, but they admit that much of man's psychical and social being remains unexplored, and that man is not yet "pigeon-holed" as to every one of his tendencies. On the other hand, pioneer thinkers like Loeb and our own Dr. Crile declare that if we could know all of any man's ancestry down through the ages, we could unfailingly predict what he would think and what he would do in any given set of circumstances.

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SCIENCE NEEDED IN BUSINESS

Psychology and sociology are certain to be the commercial textbooks of the future. The man in commerce who wants to win will be driven more and more to study the nature of the beings whose patronage and dollars he seeks. But thus far the world of commerce has studied man not scientifically, but superficially. And that is one reason why so few commercial men are able to predict new trends of trade.

Business men have not been scientific even as to economic matters. Would certain automobile manufacturers have slashed their prices, as they did two years ago, could they have foreseen the effects of the war, the country flooded with money, and a demand for automobiles so great that it simply could not be fully met? But the truth is that, acting on "hunches," certain big makers anticipated a battle to the finish among themselves, from which only the fittest could survive. Those who slashed prices, slashed in vain and at great loss, while the makers who did not cut prices had all the orders they could supply. The only net result was that the price cutters lost millions of dollars that they could have put to their credit in the banks.

I go over this ground to show that on the engineer's side of the fence is a dependable science, and that on the other side is a vast amount of guess-work. Yet the engineers and their commercial associates must do business together; they must cooperate, else neither will succeed. Makers must have properly designed cars, and designers must have an outlet through manufacturers. Therefore, since neither can get along alone, both must accept conditions as they are and make the best of them.

It will not do for makers to complain that engineers have no commercial sense, no business "punch," as I have heard them say more than once. Nor will it do for engineers to complain that men in the commercial end of business are illogical. Business men will continue to act on "hunches" and to be illogical, in the scientific sense, until psychology and sociology are more fully scientific, so that they can follow and make use of the discoveries of psychologists and sociologists.

But engineers have no excuse if they act illogically in their work, for their trail has been fairly blazed. They deal with factors that are fairly fixed. I do not mean that their work is or should be as routine as a railroad timetable. But I do mean that the business man is forced constantly to experiment, almost blindly, whereas a great deal of experimental work is saved to the engineer by the recorded experiences of men who have gone before and discovered facts, principles and formulas for their benefit.

I started this paper by saying that notable differences seem to exist between commercial men and engineers. Some of these differences I have suggested, together with what seem to be the reasons for them.

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AUTHOR'S CONCLUSION

I believe that engineers, man for man, are relatively nearer 100 per cent right than are commercial men. One reason for this is that the engineer has science working for him. Another is that men do not become engineers by accident, but through training.

A contrary condition exists in commerce. Any clean-looking young man—without training—can get a chance at the selling end of the business, and if he happens to have the knack, he is consulted as to what the public will most eagerly buy next year, and his "hunches" are given consideration by his employer. The employers themselves usually know directly very little about the fads and fancies of consumers, and they are forced to rely upon somebody's "say-so." Since the successful salesman meets the public and hears the public talk, he is supposed to be able to translate this talk into the expression of a policy for his house. I offer this as a fact, not as a criticism. Somebody *must* translate the ideas of the public for the benefit of the house, and to-day the salesman happens to be that somebody.

Where science is absent, men will always guess: they have no other way out. Sometimes they will guess right, and sometimes they will guess wrong. Nor will it help much for engineers to pat themselves on the back and thank heaven that they are not as other men. Rather engineers should be thankful that they are not compelled to grope through the dark as these other men are. The engineers should be sympathetic, meet others half-way, lending a cheerful helping hand, and remembering that responsibility goes with scientific knowledge. That means that, since engineers have the lamp of science to guide them, they have less excuse for failures than have commercial men who must of necessity stumble, and grope, and work more or less blindly.

The time may never come when commercial men can stand on a level with engineers scientifically, since their subject matter is men, which subject-matter, possessing brains, is more elusive than is matter, lacking brains. But since competition tends constantly to force commercial men to a better understanding of their subject-matter, it goes without saying that the vast gap that now separates the scientist and the commercial man will henceforth not widen, but will steadily narrow down, if only by small gains and slowly. This gradual change will assuredly bring about a better understanding between engineers and their commercial associates. For the latter will then begin to speak the engineer's kind of language, without which harmony, cooperation and fullest mutual success are impossible —I mean the language of scientific knowledge.

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DETROIT SECTION PAPERS

PROGRESS OF THE YEAR AS OBSERVED AT AUTOMOBILE SHOWS

By J. Edward Schipper

(Member of the Society)

A review of the great national automobile shows from an engineering standpoint means an inspection of the entire progress of the year. To attempt to do this in a short paper is similar to delivering a lecture on the world by the aid of a small globe. We must be content therefore with a view of the industry through the wrong end of the telescope, merely turning the glass around to observe some of the prominent heights and valleys. It is upon these that discussion will naturally be focused and it is upon these that we are most anxious to shed the light of crystallized opinion.

No one thought stands out more clearly to a student of the shows than that this has been a great year for detail. Few if any basic movements can be seen and few if any great innovations. Nevertheless it would be wrong to say that there are no well-defined trends, but even these with a few exceptions are shown by changes in detail rather than in radical departures.

PERFORMANCE, COMFORT AND APPEARANCE

To appreciate what each of the changes to be noted is intended to do, three ideals toward which we are working in automobile design may be reviewed:

Better performance is the first. This means a greater speed range on high gear, better acceleration, better economy, longer life, silence, easy starting and other factors to make the car a vehicle that can be started, operated and cared for with the least trouble and expense and with the greatest amount of satisfaction to the user.

More comfort is the second. In this phase of development is included everything that makes the car a better vehicle to ride in. Better spring suspension, upholstery, body proportions, ease of entrance, convenience in use in all kinds of weather and over all kinds of roads, convenience in night driving, in making minor adjustments and repairs, such as tire changing, brake adjusting, battery filling and even gasoline and oil replenishment.

Finer appearance is the third. What this includes is self-evident—body outline or profile, the finish and trim of the exterior and the design and adornment of the interior from the appearance point of view.

Under the heads of performance, comfort and appearance our ob-

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servations will fall; each detail considered will, in the belief of the engineer who adopted it, be a small or large step toward the betterment of one of the three. If the change has not improved one of these three things it has not been a gain from the user's standpoint although there is another consideration, and that is better manufacturing possibilities. The latter, while of enormous importance, will be neglected in order to limit the scope of this paper.

A glance at the requirements for better performance shows that insofar as the engine is concerned, many of the desired ends are closely bound up with higher mean effective pressures. This is reflected in the higher speed range, better acceleration and indirectly in other directions. The matter of higher mean effective pressure is naturally concerned with higher volumetric efficiencies. This brings us directly to the first of the observations on the cars as they are shown at the national exhibits.

The sixteen-valve four, the better designed port, larger valves, larger intake passages and indirectly even the more efficient hot-air stoves on the exhaust pipes are in evidence. There is hardly a car at the show that does not exhibit changes in the arrangement of its gas passages and an increased temperature of the mixture.

SIXTEEN-VALVE FOUR A FEATURE

This is the first year that stock sixteen-valve four-cylinder engine has been exhibited at the national shows. There are three, two of which are developments by companies that have been in the industry almost since its inception. The great importance of volumetric efficiency is recognized everywhere. The nearer that the intake stroke can come to filling the cylinder completely full, the nearer the maximum is the horsepower to be secured from a given displacement, all other points in design being equal.

The manufacturers who have put the sixteen-valve engine into actual production report a quick public demand. The advantages put forward are primarily bound up in the question of volumetric efficiency, but beyond that other claims are made, such as smaller valves for the same area, increased period of maximum opening, cleaner scavenging due to the elimination of pockets and reduction of carbon deposit. The fundamental conception that is responsible for the sixteen-valve four, and the considerations that follow as a natural consequence of it, form probably the most important point in the entire show.

It is not only by the addition of valves that higher volumetric efficiencies are sought. Several manufacturers at the shows stated that their engines give from 12 to 20 per cent more power than they did a year ago without any great change in piston displacement. Smoother ports, altered cam design, increased intake-valve size, shorter manifolds, elimination of bends in the gas passages, are universal. This year several cars were exhibited in which the intake valves were larger than the exhaust. This is a reversal of what was thought to be the best practice a few years ago.

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USE OF OVERHEAD VALVES INCREASING

Another line by which higher intake efficiencies have been sought is in the increased use of overhead valves. The overhead action in which the valves open directly into the center of the combustion chamber from above is on the increase. The old objection of noise seems to have been greatly done away with by the use of covers, by inclosing the wearing points and by the reduction in clearance due to a re-design of the valve-actuating parts. Claims of high ratios of horsepower to weight are being made by nearly all the companies having engines worked out along these lines. One newcomer in the small car field who exhibited both at New York and Chicago showed a 3¼ by 5¼-in. four-cylinder engine which developed slightly over 42 b.hp. at 2400 r.p.m. according to tests carried out in a prominent commercial laboratory in Detroit. If

$$B.\ Hp. = \frac{PLANE}{33{,}000}$$

the mean effective pressure is 106 lb. per sq. in., assuming E, the mechanical efficiency, is 75 per cent. The brake mean effective pressure is 80 lb. per sq. in. The car-weight was said to be 1900 lb., so that there would be a horsepower for every 45.3 lb. of car-weight, and a horsepower for every 4.13 cu. in. of piston displacement.

This is cited as a typical example. It illustrates what is seen on every hand at the shows this year: a reduction in car weight and an increase in available horsepower at wide-open throttle. The torque at the lower speeds however has not always been given the same attention although it can be taken as a general fact that torque curves are flattening out. This again comes back to higher mean effective pressures and is largely due to the better filling. The most important result of the high power to weight ratio is of course in accelerative ability. The public is demanding quick get-away and naturally this means high power. It also means that normal traveling has to be done at small throttle opening with a consequent low thermal efficiency.

DETAIL ENGINE CHANGES

Detachable cylinder heads are increasingly prevalent in cars having small-bore powerplants in either four or six cylinders. The difficulties of keeping the gasket tight have led to a re-design of some of the engines with detachable heads that were shown a year ago. In one design where a new head has been fitted, the change was made because it was noted that when tension was placed on the studs holding the head in place there was a tendency to draw the valve seat out of round. The amount of metal around the studs has been increased and the stud itself carried farther away from the valve. The number of studs in other designs has been increased in order to give an even distribution of pressure all over the surface of the gasket.

The educated car buyer does not like vibration and knows enough

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to ask what is being done to eliminate it. At the Chicago Show a small gasoline engine was used with a gasoline-electric car and was designed to run continuously at close to 3000 r.p.m. The counterweights on the shaft of this engine are carried as close to the plane of rotation of the crank-center as is possible, still leaving a passage for the connecting-rod. A number of improved shafts for sixes also were to be noted, three or four having the curved cheek.

INFLUENCE OF THE FUEL QUESTION

The fuel question is exerting an important influence. Some signs of the use of lower-grade fuels are noticeable on every car in the show. Hot-air stoves are more elaborate than ever before and in spite of the struggle for higher volumetric efficiencies, the use of the heated intake-manifold is growing rapidly.

The temperature of the intake manifold in winter is often below the dew point of the present grades of fuel when the vacuum in the intake is within certain limits and at the mixture proportions in general use, so that the manifold temperature is of tremendous importance. On all the cars shown there is evidence of the practical realization of the problem and it is hard to tell where the carbureter makers have ended and the car makers begun. It has been realized that with the present grade of fuel the manifold must complete the work of the carbureter or at least not detract from it. It is hard to say, looking at the show chassis representing the thought that has been put upon this point, whether the carbureter has been reduced to a simple mixing contrivance with the work largely carried on by heat in the manifold.

If the heated manifold is to do the work, it seems impossible to have the same design for use in the hot summers of the South and in the cold winters in the North; particularly as in many instances the fuel is more volatile in the warmer climates. Prospective car buyers who keenly follow developments in the automobile engineering field have already started to ask that question.

Several makers exhibited engines with thermostatic or other control of the water temperature. Some used the shutter controlled by hand, and at least one inquirer was heard to ask if the shutter were thermostatically controlled, a development at present under consideration. It has always seemed incongruous to see a $3,000 car with a piece of newspaper across the front of the radiator. The temperature question seems to embody some of the most important considerations that are before the automobile engineer of to-day. The question is being wrestled with by engine builder and carbureter maker alike and the necessity of cooperation can not be too well realized.

ENGINES GENERALLY NOT OF LIGHTER WEIGHT

Generally speaking the weights of engines are not less than they were at the shows in the beginning of 1916, although the engines are developing more power per weight unit. Reciprocating weights are

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still less but it is doubted if the aluminum alloy piston has taken any firmer hold. Engine manufacturers generally have learned how to make iron pistons of less weight. Just as the multicylinder engine has forced better performance from the four, so the aluminum piston has forced better iron pistons. Some of the latter are now made of such light weight that the direct saving in weight by using an aluminum piston with its heavier section is quite small and negligible except at high speeds. It is noticeable that the aluminum piston is in far greater favor among the car manufacturers who make their own engines than it is among those who make engines for the trade. Where aluminum pistons are used they seem to be longer than those first employed.

Some new members in the ranks of the V-engine manufacturers demonstrate what was predicted generally two years ago, that the type had a definite field and would increase. One of the new eights is a Knight and the other an overhead poppet type. Both are produced by companies noted for quantity production and hence whose endorsement carries a great amount of weight. Talks with those showing the type and others indicate that on every hand it has been considered a matter of cost and performance. Some believe that they can secure better performance from the eight for the same cost than from the corresponding six, and vice-versa. The shorter, stiffer shafts of the V-engine, as well as the smoothness of power flow, are dwelt upon at length by the demonstrators of the type; those who speak on the other side mention equal performance with easier maintenance, thus leaving the question open to debate with a growing popular demand for the V-type.

PRESSURE OIL-FEED INCREASING

One of the points most frequently asked about by the show visitor is the oiling system of the car. The increase in pressure-feed systems is particularly noticeable. The increase in number of pressure systems and in the amount of pressure used has been almost in direct proportion to the increased piston speeds of the engine. With many designers stating that a piston speed of 2000 ft. per min. is desirable for passenger car service naturally a great amount of attention has been focused on the maintainance of the oil film.

This is a trend that has been growing. A census taken at the shows in 1912, showed that 10 per cent of the models used pressure feed and 20 per cent a combination of splash and pressure. This is a total of 30 per cent putting the oil into the main bearings under pressure To-day 30 per cent of the chassis models use full pressure feed and 35 per cent splash and pressure, or a total of 65 per cent feeding by direct pump pressure to the bearings. It is not uncommon to have the oil pressures as high as 40 lb. per sq. in., with the oil exercising a marked cooling effect on the bearing. The question of taking the heat away from the oil is an important one, and recent reports show that special provisions are under development for this purpose. In fact,

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crankcase temperatures are being studied more carefully than ever in an effort to preserve the quality of the oil. This is particularly important in view of the great amount of unburned fuel that is finding its way into the crankcase and destroying the quality of the lubricant.

In cooling very little is to be noted from a superficial examination of the show cars. Pump cooling leads with about 66 per cent of the chassis using it. With the detachable cylinder head it has been found necessary in a few instances to increase the amount of water around the head. More care is being used on the newer engines to eliminate steam pockets and hot spots due to masses of metal. The water is being carried closer to the exhaust passages and also closer around the spark-plugs.

GAS AND COMBUSTION CHAMBERS REFINED

Valve actions do not appear to be greatly different. In the overhead rocker-arm type there seems to be a tendency toward a differential rocker. With this the travel of the rocker on the push-rod side is less than on the valve side. This permits the use of a lighter spring for closing the valve, owing to the leverage. Another gain claimed is in a quicker lift with a longer maximum opening, a detail that again reflects the effort for higher volumetric efficiency. On the other hand others, while conceding some of the advantages, have not adopted it on account of the difficulties entering into replacements. The service station would be forced to carry an entirely different set of valve parts.

It is in the combustion chamber that some of the most important changes of the year have taken place. By changing small details and by an alteration in the gas passages, the power of the engine has often been increased to a surprising degree. One maker has made the gas passage below the valve in venturi shape with the throat of the venturi just below the valve and so arranged that the valve seat forms a continuous part of the venturi wall. This is on the small four mentioned as part of the gasoline-electric unit at the Chicago Show.

Before leaving the combustion chamber a detail in manufacturing practice may be mentioned. This is the accuracy being required for equality of combustion-chamber volume. One manufacturer of fours insists that the combustion chambers check within 0.20 cu. in for accuracy. With the great care taken in balancing the high-speed engine the need for accuracy in this respect is self-evident.

A development of the powerplant that is receiving more attention every year is its accessibility. The national shows are visited by large numbers of repairmen who come for the purpose of seeing developments from their angle. Naturally, one of the first considerations is accessibility. Engines that can have the pistons pulled out from the bottom without removing the crankshaft are well liked and are being looked for. This question has been given attention wherever feasible.

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The detachable cylinder head involves the gasket question and there is a great amount of difference of opinion as to whether the gaskets can be kept tight with the high-compression engine. Another point is oil-pump location and the ease with which the pump can be removed. One new stock engine used in several cars has the oil pump so located that it can be removed quickly by taking four studs from the bottom of the case.

CLUTCHES MUST DISENGAGE WITHOUT DRAG

After the power has been developed the next question is to transmit it efficiently; the improvement in powerplants is naturally reflected in the transmission units throughout the chassis. The first of the units, the clutch, shows the improvements clearly. Examining fifty-four stripped chassis at the New York Show and the fifty-two at the Chicago Show, one of the facts that stands uppermost is the decrease in the number of adjustments. The majority of clutches examined were those made by standard parts makers, who seem to show a practical unanimity of aim. This is to secure the lightest possible efficient clutch for the torque and power delivered, and to have this clutch automatic as regards lubrication with wear-compensation in the mechanism itself. Many of the clutches shown had no adjustment except that on the pedal. It was said that some of them could be used for 50,000 miles or more without attention.

Clutch linkage has been altered. One of the newer cars exhibited has a clutch that can be disengaged by the pressure of the hand. This means that the travel of the clutch parts for disengagement must be small, because the distance that the pedal moves is about the same as usual. Another possibility is increased area of frictional surface with a lighter engaging spring. The use of fewer disks on the disk clutch is increasing and reduces the necessity for long travel in disengaging. This is one of the factors that is making for more easily acting clutches.

The increase in the speed of rotation of the clutch parts, owing to higher gearing at the rear axle, has reduced the torque and consequently has its effect on clutch design. The rotating parts of the clutch have been made of lighter weight because of the tendency toward quieter gearshifting. No great increase in the use of clutch brakes was noted, but on inquiry it was found that quick release is being made a particular study, and when it is secured the clutch brake has been done away with by some makers. This quick-acting release simply prevents drag while releasing. It is this drag of the clutch when it is not fully released that causes the clash in shifting gears.

GEARBOXES NOT CHANGED

As far as the gearbox is concerned, little change was noted. The unit powerplant is still gaining with a notable increase in the use of the S. A. E. Standard bell housing. There has been some simplifica-

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tion in the mounting of the control levers and also an increase in accessibility. Iron is used to a greater extent in gearbox housings this year because of the higher price of aluminum and also because of its non-resonant qualities. The unit powerplant is now used on 77 per cent of the chassis.

A feature in transmission units that will bear watching is the use of the electric transmission. At the Chicago Show three cars had three different forms of electric transmission. In addition one car showed the magnetic gearshift as standard equipment.

The percentage of full-floating rear-axles in the chassis listed has decreased slightly. It is now 43 as compared with 52 a year ago. The use of the semi-floating axle has increased from 23 to 25 per cent. More spiral gears are being used because it is now easier to get the equipment for cutting them. They are now on 70 per cent of the chassis models.

SUSPENSION AND BRAKES

One of the most notable changes of the year is in spring suspension. This may be realized from the fact that the models with half-elliptic springs are more than twice as numerous as those exhibited a year ago. The percentage of cars using half-elliptics is 36, while last year they were on 15 per cent of the cars. The decrease has come in the three-quarter elliptics. A year ago these were employed on 42 per cent of the chassis; they are now on 27 per cent. The percentage using cantilever springs remains the same. There is a tendency toward placing the springs directly beneath the frame instead of to the side.

Probably the spring change has been influenced more than by anything else by the use of Hotchkiss drive, which is now on 44 per cent of the chassis models. The half-elliptic springs, along with the other types, have been lengthened on many of the cars. The study of easy suspension is one of the most important factors in the comfort of the present chassis. The increased deflection per unit of weight gained by longer springs has resulted in a re-design of brakes in some cars. This is particularly true when the Hotchkiss drive is used, as there is always danger of brakes binding if the center and radius are not carefully laid out.

Brake details have been given more attention this year than for some time in the past. One of the reasons is in the increased use of Hotchkiss drive. The points in which the brake designs are better are particularly the equalization, the elimination of rattle and, as mentioned previously, the proper layout of pivot center and link radius. On many cars a continuous-cable equalizing system is used in which the cable runs over pulleys; others are using cable to supplant the linkage.

Probably everyone is familiar with the operation of the vacuum brake, in which the suction in the intake manifold, amounting to a

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few pounds per square inch, is converted into a large force by the use of a piston of large area. A system of levers reduces the travel and multiplies the force correspondingly so that a powerful pull on the brake rod is obtained.

ELECTRIC EQUIPMENT REFINED IN DETAIL

It cannot be said that any radical developments are to be noted in electrical equipment. There has been further improvement in the mounting of some of the generators and starting motors, but the changes in design are slight. One prominent manufacturer of an eight-cylinder car has shifted his generator up with the fan and drives both from a V-belt, giving a very compact layout.

The Bendix gear is seen on what would seem to be on casual inspection a considerable majority of the cars. There are many magnetic engagements for the starting motor and a few mechanical shifts.

The use of two-unit starting and lighting systems has increased. Probably the increased engine speeds are responsible for this to a great degree, as well as the increased simplicity of generator drive. Another point in which increased simplicity is notable is in the generator-output regulation. The three-brush system seems to be on the increase as compared with a year ago. The vibrator type of regulation is also more than holding its own, with bucking coil and others in the minority. No figures have been compiled on the percentages using the three types, but careful observation will confirm the trend toward the two first-mentioned types.

It is noticeable that there are not nearly so many complicated systems as existed two years or even one year ago. One electric company has brought out during the year and incorporated on some of the cars at the shows a thermostatic unit that alters the charging rate to conform with the temperature conditions. This is a simple device when analyzed, which simply switches in a resistance when the temperature of the generator increases above a predetermined amount. This temperature is generally about 150 deg.

Some real development work has been done in the ignition field, as is quite evident on standard equipments. Probably the most noticeable feature is the better and more compact combination of the distributor and generator. The action of breaker mechanisms has been speeded up so that there is no trouble in handling even the most rapid of high-speed engines. One manufacturer has brought out a new closed-circuit system in which the movement of the contact point is only 0.006 in.

TENDENCIES IN USE OF TIRES

In tire equipment there is an increase in the use of the straight-side type. Another noticeable feature at the shows was the large number of non-skids fitted on the rear as stock equipment. The cord tire is listed on a larger percentage of chassis and in a lower price field

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than was the case a year ago. It is noticeable that while car-weights have been decreasing there has not been any great tendency toward a decrease in the size of tires, the tendency being toward over-tiring rather than in the opposite direction.

BODIES NOT ALTOGETHER SATISFACTORY

Great improvement has been made during the year in the proportioning of body space, particularly as regards the front compartment, but in many instances the driver's seat is actually uncomfortable. In some the driver is comfortable after he has seated himself, but while entering and leaving the seat he is very uncomfortable. A large man often buys a low-priced car and he is the last man to believe that the room in the driver's seat should be proportional to the price paid.

Naturally, a longer wheelbase is to be expected on the higher-price car, but with reasonable proportioning and care in working out the position of the pedals much can be accomplished. It was interesting to watch some of the taller men who were invited to sit in the cars by the ever-alert salesmen. If the salesman were wise he would invite the more lengthy prospects to sit in the tonneau because there were several cars in which the knees would strike the lower rim of the steering-wheel. All in all, however, the situation in this respect is not so bad as it was a year ago. In fact, in a few cases one of the big selling arguments for the car is its driver's space. The driver is the owner in such a large proportion of the 3,000,000 cars on the road that he deserves considerable attention. He is the man that pays for the car, and should have as much comfort as his guests who occupy the tonneau.

From a superficial inspection of the color designs at the shows the impression is gained that manufacturers are looking for other colors than black. The colors must be durable and that is the stumbling block of the brighter combinations. There are a number of grays and greens, however, this year, and they afford a pleasant relief. Probably if the truth were known some of these other colors are not much more difficult to take care of than the more somber black.

There is an increase in the number of four-passenger cars and a decrease in or practical vanishing of the three-passenger cloverleaf type. The four-passenger cloverleaf of today is really not a cloverleaf at all, strictly speaking. If it were, the rear passengers would not have enough room. This was the objection last year and designers have given up the idea of cramping the rear passengers simply for the sake of having the body a true cloverleaf. The four-passenger roadster, which preserves the roadster lines with doors only at the front and with entrance to the rear through the aisle between the front seats, is very popular.

CUSTOM-MADE BODIES

Some purchasers desire individuality in cars just the same as they do in clothing, shoes or in other lines. Some of the biggest dealers

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have increased their sales and their profits by putting custom-made bodies on stock chassis. The salons at New York and at Chicago were well attended and the proportion of actual buyers to attendants was far higher than at the big national shows. In New York one rebuilt British chassis fitted with a fine example of the custom-body builder's art sold off the floor of the Astor for $14,000. This same idea carries back through all the price classes. On the street at New York, just outside the Grand Central Palace, there was a row of cars fitted with some exceedingly neat speedster bodies painted attractive colors. These sold at an advanced price, and although the chassis is one that is low in price, these little cars with their attractive bodies appealed to a very high class of buyer.

The door fitting should be improved, as shown by an inspection even of the carefully prepared show bodies. On one side the doors would be tight and on the other loose. The shape of the center cowl can also be improved. On one car exhibited a real use was found for the center cowl by providing in it a place where the rear windshield could be housed. Many at the show believed that the rear windshield is coming, and it has been said that once it is tried the user never wants to be without it.

Another place where improvement is suggested is in the contour of the upholstery of the back of the seat. After sitting in perhaps fifty or sixty different cars at the New York and Chicago shows, the different effects of the shape of the seat back cannot help but strike one as important. In some the bulge is too high, in others too low. In some it is necessary to sit exactly vertical and in others one actually leans forward if sitting well back in the seat. The most comfortable position seemed to be that in which one leans slightly backward with the bulge in the leather fitting the natural curve of the back. Care seems to be particularly necessary when the seat has a pronounced rake; the forward inclination is then imparted if the curve of the back is not correct.

The arrangement of the extra two seats on the seven-passenger car is better this year on some cars and not very good on others from the standpoint of both appearance and comfort. One maker folds his extra seats under the rear seat, giving perfect concealment. Another maker of four-cylinder cars has a particularly good arrangement with well-upholstered extra seats. These fold into a deep center cowl and the backs are amply padded. A long ride in seats such as these is not the rather painful experience that it is on some of the hard seats without proper backs.

One last feature that needs only mention, as its practicability seems well realized, is the car for all times of the year. For the man who travels with his top up in summer the permanent-top type is supplied, and for those who like nothing but the blue sky overhead the convertible types are available. Both of these were present in great

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numbers at all the shows and both are greatly improved, as regards the removal of the troublesome rattle, compared with the models of a year ago.

NOVELTIES AT THE SHOW

There is always a novelty or two at the shows. This year at New York a front-driven car drew much attention. The steam car, which is not new with us, but which for some time has been absent from the floors of the Grand Central Palace and the Coliseum, was always surrounded by throngs. Another newcomer at New York had a sixteen-valve overhead-camshaft engine, and still another showed an electric which was simplicity personified, the motor being mounted directly on the rear axle and acting both as a driving unit and as a differential.

On the front-driven car a stock powerplant is used, with the engine mounted as a unit powerplant in the usual manner, but the drive transmitted forward to a live front axle. There is a dry-disk clutch within the bell housing, and the clutch shaft, instead of transmitting the drive directly to the main shaft of a gearbox, carries a worm. This meshes with a Hindley worm wheel with floats on the differential housing. From this wheel the various reductions are obtained by an orthodox gearbox mounted transversely across the front of the car directly below the worm gearing. All the weight at the front end is carried upon a dead axle with the live axle transmitting the drive from the gearbox and differential and mounted flexibly on each side of the transmission unit. There is a universal at the point where the drive-shaft leaves the gearbox and another at the point of connection to the front wheel. This gives a full universal action for the driving member and permits of free steering, which is accomplished by a central pivot located directly in the axis of the wheel.

BETTER WORKMANSHIP SUGGESTED

It seems fitting that a plea for better workmanship, particularly on bodies, should be made. The buyer of to-day looks into the matter of careful workmanship to a greater extent than is realized by many who deal with the manufacture of the car rather than its sale. The exterior outline has been given a great amount of attention, but as in buying a house the purchaser looks not only at a beautiful exterior but at the fitting of the woodwork and the care with which the trimming is applied. We have a firm foundation in the chassis, a beautiful piece of architecture in the body; now let us have beautiful workmanship in the interior.

One of the things commented on at the shows was the growing size of the vacuum tanks. Some of the eight-cylinder cars carry tanks that are particularly large and of which the weight must be considerable. It has been suggested that the vacuum tank could be built directly into the cowl. There does not seem to be any necessity for having a cylindrical tank. A flat cowl tank, having a capacity of a gallon and

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with the vacuum-feed system incorporated would not take up a great amount of space. It would be an advantage to have a good supply of fuel close to the engine where it can become warm.

The distinct increase in the number of tilting steering-wheels should be mentioned. One of the most difficult parts of body design is to observe all the correct proportions and at the same time permit easy entrance into the driver's seat. The tilting steering-wheel overcomes this problem very neatly.

Some of the big companies can purchase leather in such enormously large quantities that they can use the true product for upholstery. Others believe that some of the substitutes can be used just as satisfactorily. The cars produced in 1915 used a considerable amount of this artificial material, and on the whole it cannot be said that it was satisfactory. It cracked in cold weather, soon lost its luster and peeled wherever any chafing existed. The cars of 1916 have not shown these difficulties to such a large extent. It may be, of course, that they have not been out long enough, but with the increasing price of leather the question of leather substitutes becomes highly pertinent and is one upon which every manufacturer must be fully informed.

WEAK SPOTS IN CHASSIS

We have a few weak spots such as chassis lubrication, pedal layouts, incompleteness in finish of the body trim and in the handling of the fuel situation. The first mentioned is probably one that is least studied and yet, from the car owner's point of view, is the most important. In one car shown at all the shows five grease-cups are placed under the car, at the center where the drive-shaft is divided, and not one can be reached handily except by climbing beneath. Other makers have studied this subject to some extent, and a few are substituting oil instead of grease, a practice which may grow.

In pedal layouts the positions of the clutch pedal and the accelerator are the two worst offenders. It is difficult to put the foot quickly upon some of the clutches, and for driving in traffic an uncomfortable clutch is very bothersome. The accelerators on some cars are sufficient to give the driver housemaid's knee or some other uncomfortable affliction, after a long drive. One maker showed an accelerator with which the foot can be always kept flat on the floor, the pedal moving sideways for speed changes. This seems to have possibilities, as the greatest strain with the ordinary accelerator comes from the necessity of having the foot resting continually on the side or on the heel.

It is only in the details, however, that there are a few signs of lack of attention. Broadly speaking, this has been a year of great progress and, although we cannot come forward with a long list of radical innovations, the gains here and there in important particulars and the strides evidenced by the many improved details make the show season of 1916-1917 an important milestone in the automobile industry.

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DISCUSSION

C. C. HINKLEY:—The sixteen-valve engine should be used only when excessively high speeds are required. I believe we cannot use it commercially on cars operating most of the time at speeds less than 30 m.p.h. I think that the expense connected with the sixteen-valve four is not commensurate with its commercial value, because it is nothing more or less than a modified T-head engine with all its attendant difficulties. The T-head engine is limited in its functioning, owing to the excessive size of the pockets over the exhaust valve, which prevents the use of maximum pressures, such as are employed to-day; the reason for this being, as I have analyzed it, that the dead gas is formed over the exhaust-valve pocket, and never gets away. Gas is always present in a pocket and is compressed by the incoming charge. Ultimately, when a high compression is used, the gas becomes incandescent and ignites prematurely, the result being an engine knock.

I can see no reason for twin exhaust-valves. We know by dynamometer test that the exhaust valve is not so important in its functioning as is the inlet valve. There is a reason for the twin inlet-valve, because it has been determined that the exhaust can be considerably smaller than the inlet, in a ratio of at least four to five. We must consider whether the manifold capacity is sufficient to take care of the twin inlet-valves. When we increase the capacity of the inlet manifold we decrease the gas velocity correspondingly. When we decrease the gas velocity, part of the carbureting feature of the manifold is taken away from it; as a result the mixture condenses rapidly in the passages and there is consequently loading of the engine under heavy pulling, or in the low-speed wide-open throttle condition. The one other way to prevent such condensation is by the application of excessive heat, which lessens the volumetric efficiency. If the volumetric efficiency is decreased, owing to the heat used to take care of the twin inlet-valve, what is the value of the excessive valve capacity on the inlet side?

I have tried overhead valves myself in several ways, and I am not very enthusiastic over the idea. To my mind the only correct way to build an overhead-valve engine is to lubricate all the moving parts. The average overhead-valve engine is lubricated in a hit-and-miss fashion, which only increases the wear and the attendant noise. I believe that the old objection of noise has not been greatly overcome by the use of covers, because I have never been able to muffle noise with covers.

"The demands of the public are for quick get-away, and naturally this means high power." I do not know what Mr. Schipper's meaning is in that sentence, unless it is a high torque, with quick get-away; this in connection with the lower rear-axle ratio may mean high power or the sensation of high power. And he states that our "normal" traveling has to be done at small throttle-opening with a consequent low

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thermal efficiency. That is something like saying that "our poor relations are always with us." We have always had that condition. I do not know really how we can get away from it; the only protection we have is that due to some sort of an economizer action in the carburetion, when normal driving is done.

I believe the greatest trouble with detachable cylinder heads occurred when there were not sufficient bolts. Valve distortion is due entirely to the location of bolt bosses adjacent to valve pockets, but the error is in the design rather than in the principle.

DETROIT FUEL ORDINANCE

We have recently passed a city ordinance in Detroit by which we will standardize the fuel. We will not try to tell the oil people what they shall make; we are not going to try to get a guarantee from them. What we do want is to have tanks properly labeled so that we will know what we are buying. The ordinance provides that 20 per cent of the fuel shall distill off at 220 deg. F., that 50 per cent shall go off under 300 deg., and 98 per cent shall go off at 450 deg.

Mr. Schipper states that the use of the heated intake-manifold is gradually growing. By that I understand he means the intake passage, and does not mean the pipe from the hot-air stove to the carbureter. It is my belief that there are two places at which to heat the charge; one is in the intake passage, and the other is before the air reaches the carbureter. The efficiency is less when the pure air is heated before reaching the carbureter than when the charge is heated in the intake manifold. All attachments between the carbureter and the stove should be so arranged that they can be disconnected during the warm months. The reason for this is that when the charge of gas is passing the carbureter, the lighter elements (the pure air content) will always take to the center, while the heavier elements will cling to the pipe. In heating the intake the heat is applied where it is most needed, that is, to the raw fuel, and not to the air forming the bulk of the charge.

Most of our engines have been of too light weight. The greater part of our main bearing trouble is due entirely to crankcase distortion, and this is particularly so if aluminum cases are used. We have lately been experimenting with what we call the "dry-wringing" of crankshafts; under high torque, with an electric motor, it is an actual fact that it is impossible to put a bearing that will keep its form into a case under the dry-wringing process, unless it is very securely ribbed. This testing work is no more severe than what the shaft is actually put to in service. I know of many designs in which the main bearing is bound to distort after being in actual service, and to give trouble.

The aluminum piston is all right if handled properly. We are machining tapered aluminum pistons having clearances of 0.025 in. at the top land, 0.015 in. at the second land, 0.009 in. on the third, 0.006

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in. at the top and 0.004 in. at the bottom of the piston skirt. We have recently been experimenting with aluminum and cast iron pistons. We have run a thirty-day break-down test with wide-open throttle, at 1700 r.p.m. and 37 hp. With the cast iron pistons, the center of the head invariably failed and could not be kept in, owing to the excessive heat.

The manufacturer who insists that the combustion chambers check within 0.20 cu. in. is probably working on a high-priced proposition and can afford to machine the combustion chambers; for the average-priced car, such as most of us are trying to build today, such a degree of accuracy is unnecessary.

REQUIREMENTS FOR COMFORT

I have heard a great deal about comfort, and it seems to me we ought to lay down a short and concise rule as to what is needed in the way of comfort in the driving compartment. I have made a study of that and have come to the conclusion that bodies can be called comfortable when their dimensions lie within certain limits and uncomfortable when they are beyond these limits. I would like to state what the limits are.

The distance from the clutch pedal measured over the edge of the front-seat cushion to the seat-back should lie between 37 and 38 in. on the average car. The distance can be made greater if desired. If it is less than 37 in. the result will be what is called a slightly uncomfortable car. The shorter this distance the more uncomfortable it gets. The height of the cushion from the floor can vary from 13 to 15 in. and the depth of the cushion from 16 to 18 in., 17 in. being preferred. The distance from the lower side of the wheel to the cushion can be between 7 and 8 in. The distance from the wheel straight back to the trimming should be from 13 to 15 in. The width across the body at the hips of the driver should not be under 42 in.; across the door, that is, between the front hinges where the door breaks, it should be about 41 in. If the body is too flat on the side, it has a tendency to converge too rapidly, giving the impression of being cramped in the knee room; this is especially the case in a center-control car.

CORNELIUS T. MYERS:—To my mind two things should be considered by engineers with more application than has been given them in the past. One is the question of chassis lubrication. It is of vast importance that we give the small points of the chassis the engineering application so that they can go for a long time without any attention and can give service almost indefinitely. Mr. Schipper pointed out that a vast number of cars go into the hands of men who look after them themselves, or do *not* look after them. The small points are things on which we must concentrate, the things that make a foolproof car. They are not necessarily expensive in the long run, although they may be at the start.

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NEW IDEAS FOR SUSPENSIONS

Something else that should receive a great deal of attention is the spring suspension, and I think many of our old ideas on that question will be exploded. The paper* on Dynamics of the Automobile, given at the last Annual Meeting of the Society, deserves considerable study, because the subject is so important. An easy riding car has ordinarily been considered as one with a long wheelbase. Mr. Akimoff states, and I believe he is absolutely right, that the shorter the wheelbase the easier the car will ride, all other things remaining the same. Most of us have had the contrary opinion, based on the fact that a great many cars having long wheelbases ride more easily than those with short wheelbases. The riding qualities depend on factors entirely outside that of the wheelbase; one of these factors is the weight.

It is ordinarily believed that the lower the center of gravity the easier the car will ride. This is not so, as anybody that has had experience in driving railroad locomotives knows. The higher the center of gravity, the more slowly the beam will vibrate. The period has been very much increased. Two things will make spring suspension better and cheaper: an effective decrease in the wheelbase and an increased distance of the point called the center of gravity above the center of oscillation of the car.

C. F. JEFFRIES:—The vacuum brake may be a good proposition, but a number of vacuum tanks will not work on an eight-cylinder car without a great deal of tinkering. The pressure in the manifold does not seem to be low enough to lift the gasoline up to the vacuum tank, let alone apply the brakes of a car.

OBTAINING COLORS FOR BODIES

ALBERT I. STEVENS:—The color matter that Mr. Schipper referred to is really more a matter of factory practice and cost than it is an engineering matter, but it is more serious probably than many of us realize. I have known of the time when a certain ingredient used in making red was so scarce that the entire market of the country afforded only 500 lb. This was bid for by various color companies in the East, and the price went up to a point where it was entirely out of proportion to the value. Leaving out the question of cost, there is also the feature that whoever got that ingredient had no assurance that he could get any more like it.

In the modern system of baking, which is very rapidly coming to the front on bodies as well as on the metal (or on what were heretofore known as metal) parts, the application of heat will change and alter to a great extent the shade of the color. We will have a "Joseph's coat" effect all on one body, if great care is not used. Most of these bodies painted on the quantity-production basis are flushed or dipped

*Remarks on Dynamics of the Automobile. N. W. Akimoff. S. A. E. BULLETIN, December, 1916, p. 262.

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in the paint or it is put on under pressure (flooding processes of various kinds); the various systems require a large amount of material—one color being used at one time—and if the color should happen to be changed at the end of a season, there would be an immense loss in the goods on hand in the tanks.

AUTHOR'S CLOSURE

J. EDWARD SCHIPPER:—I believe that we cannot say very much about the sixteen-valve engine as yet. It has not been commercially on the market long enough. There are certainly a few that believe very strongly in it, and I know ten or twelve experimental jobs have been tried out.

Mr. Hinkley suggests the necessity for twin intakes rather than the twin exhaust. That almost suggests a twelve-valve engine with single exhausts and twin intakes. The manifold design is no doubt a compromise. We must compromise between the velocity in the intake manifold and the possibilities of volumetric efficiency with a preheated charge. We have all realized that the preheated charge must come, and naturally it will give a lower volumetric efficiency.

The workmanship on the aluminum piston really seems to be the critical point in the whole situation. One company had to send men all over the country to take out aluminum pistons and put in iron ones, simply because of poor workmanship. The question of clearances is so important that a little deviation means a great deal of trouble. Deviations occur easily unless we watch that particular department all the while, and with big production it is hard commercially to maintain the clearances and small tolerances that are allowable with aluminum pistons.

The question of pressure feed, as Mr. Hinkley said, is important, and no doubt the use of such systems will increase. The splash system is inadequate, and also inaccurate. It might be well to consider the pressure that is exerted on the oil scoop as it cuts through the bath of oil at each revolution at high speed. It is true that the oil pool does not have time to close. In an engine revolving at 2800 to 3000 r.p.m., the pool of oil in the sump has not come together by the time the scoop comes around on the next revolution. At the same time a considerable amount of pressure is everted and also a considerable amount of impact. I know of one case when a special engine was rigged up for a test, and the scoop was battered off the connecting-rod. Those particular scoops were brass scoops, brazed on. If the impact was sufficient to take off a brazed scoop, it might even have an influence on balance.

ROOM IN DRIVER'S COMPARTMENT

Suppose *A*, Fig. 1, represents the entrance, *B* the side of the car, *C* the seat and *D* the steering-wheel. This dimension *E*, that is, from the point of entrance up to the steering wheel, is of great importance.

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The door might be a large one, but it is of no value whatever unless the clearance space at *E* is sufficient, because a man entering a car does not pass through the whole door; he has to squeeze between that

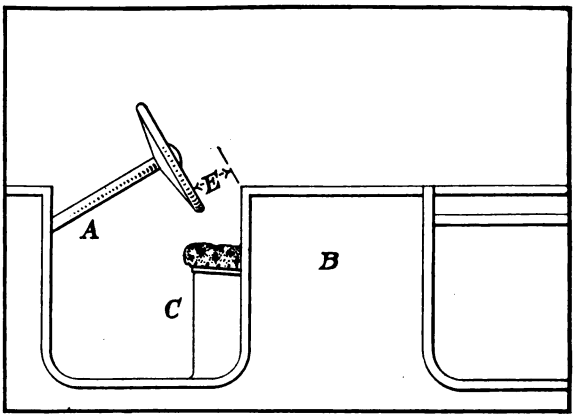

FIG. 1—SEATING ARRANGEMENT OF CAR

middle point at *E*. I have measured cars in which the space from the steering-wheel to the corner of the entrance was only 4-in., and it takes a pretty good contortionist to get through that.

I am not advocating the vacuum brake, and I did not mean to imply that in the paper. I was speaking to an engineer the other day and he mentioned the fact that when the spark is off or if the engine is dead or not in operation, there is no vacuum to work with, which I think is a good point.

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METHODS OF COMPARING AUTOMOBILE PERFORMANCE

By Walter T. Fishleigh

(Member of the Society)

From the earliest days of the automobile industry we have heard much about "automobile performance" and "car ability." The price set upon his product is in general the manufacturer's estimate of the willingness of the public to part with so much money for so much automobile performance. The importance of performance has long been realized by the automobile-buying public. Performance is to an automobile what character is to a man. It is almost as hard to define; it has almost as many disconcerting factors; it is almost as jealously guarded by manufacturer and owner alike. The subject has been discussed for years by every well-organized engineering department and can be and has been approached from half a dozen different angles with apparently inconsistent results; it includes the whole problem of design from radiator to tail-lamp.

The general idea of performance is old as applied to automobiles, but the standard for it has been raised at an alarming pace in an effort to keep up with improved design. Only fifteen years ago, the standard was based largely upon the single-cylinder "jump-about," which was conceded to be a star performer if it would run most of the time and stop when desired, without regard to such trifling items as acceleration, speed, fuel economy or general physical convenience of the riders.

The advent of the eight and the twelve, the rapid improvement in the light four and six, scientific reduction in car weight without material sacrifice in riding comfort, revised notions of piston speed and gear ratio—each of these has in the past three years drawn special attention to the matter of performance; each in so doing has emphasized the fact that an accepted and accurate method for estimating, measuring and comparing automobile performance would be of tremendous value. In the midst of varying claims by manufacturers for their product, varying tests purporting to show performance of a particular car, varying formulas for estimating everything from tractive effort to so-called car-ability, a genuine demand has grown up for an agreement upon tests for determining if possible a definite formula or record for relative car-performance.

FACTORS OF AUTOMOBILE PERFORMANCE

The factors that make for good car-performance have been more or less agreed upon. The tests that show the degree of car performance or car ability are pretty well recognized, and there is little doubt

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that if a new model were to be tested for "general performance," the following tests or their equivalent would be made:

1. The car would be driven upon good pavement to determine its range of operating speed; that is, the lowest and highest speeds at and between which the engine and car operate steadily and successfully.

2. The acceleration would be tested, probably starting at the lowest steady operating speed and determining the time necessary to accelerate to the maximum speed; or perhaps the test would be run between two arbitrary limits, as from 5 to 55 m.p.h.

3. The car would be operated on steep grades or hills. This test would involve both high gear work at different speeds, and operation in the different gears.

4. Tests would be made upon the road or upon a speedway to determine fuel economy; that is, miles per gallon of gasoline. Economy runs, to be scientific, definite and comparable, should be made at a number of definite speeds, for example at, 10, 15, 20, 25, 30, 40 and 50 m.p.h. The results will give an economy curve that tells the complete story of economy at various speeds.

5. The car would be run over good, bad and indifferent roads, at various speeds, and going through various maneuvers to determine "riding comfort." This factor is the resultant of many items in design, such as weight, wheelbase, spring suspension, engine characteristics, body and seat design.

For completely trying out car performances, tests would be run to determine (1) range of operating speed, (2) acceleration, (3) hill-climbing ability, (4) fuel economy, (5) riding comfort. Other things being equal, acceleration and hill-climbing ability are both directly dependent upon, and measures of, excess drawbar pull per pound of weight over that necessary to propel the car at a given speed against the usual road, wind, tire and frictional resistances. If the inertia of rotating parts be neglected, the one is directly proportional to the other. If inertia of rotating parts be considered, two cars of equal weight and hill-climbing ability will show accelerations slightly in favor of the car in which the inertia of rotating parts is the smaller. Likewise of two cars of equal weight and accelerating ability, that car will be the better hill-climber whose moment of inertia of rotating parts is the larger. In any event, however, this variation due to difference in inertia of rotating parts is small.

Either the relative acceleration of two cars or their relative hill-climbing abilities will give a simple, understandable and accurate means of comparing these cars as far as excess drawbar pull is concerned. Acceleration or "pick-up" is easily and accurately measured with well-known precision instruments, which are available in all parts of the country without great expense. The approximate hill-climbing ability can be calculated at any speed, once the acceleration at that speed or the acceleration curve covering the range of operat-

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ing speeds is at hand. For these reasons, it is proposed that acceleration tests be agreed upon as the standard factor in car performances for indicating excess drawbar pull. Complete performance then becomes the resultant of (1) speed range, (2) acceleration, (3) economy of fuel and (4) riding comfort.

The range of successful and steady operating speed is much emphasized to-day, both minimum and maximum speeds being important. The lower the minimum speed and the higher the maximum speed, the better the performance. Many operators place a premium upon low operating speeds, others upon high maximum speeds; the use of the straight operating range would seem to be a fair solution, thus increasing the value of car-performance with either lower or higher operating speeds, but not in direct proportion. For two cars, otherwise the same, but the first with a speed range 10 to 40 m.p.h., the second 5 to 65 m.p.h., the performance of the second would be two times that of the first.

Economy of fuel or mileage per gallon is a function of the efficiencies of the engine and power-transmitting units, of the size of the engine, of gear ratio, and of weight of the entire car. Other things being equal, that car which shows a consumption at any speed of 20 miles per gallon is a better performer than the one that shows 18. The fourth factor—riding comfort, as determined by weight, wheelbase, spring suspension, engine characteristics and design of body and seats—is evidently one that cannot be expressed once for all by a formula. Moreover, it cannot be defined in mechanical terms or measured by any mechanical yardstick. It is an item dependent upon the judgment of the individual, in which the personal equation is not only present but predominant.

We can state that automobile performance varies directly as speed range (S), acceleration (A), economy of fuel (E), and riding comfort (C); where S = speed range in high gear, in miles per hour; A = average acceleration of car in feet per second per second over the complete range of its operating speeds; E = average fuel economy, over the complete range of its operating speeds, in miles per gallon; and C = riding comfort factor, which must be determined by each individual.

On account of the item C, complete car performance or car ability cannot well be determined once for all by rigid test, nor estimated in any simple and practical way. The item C must be left to personal judgment. In considering car performance, however, the other items (S, A, E) are each susceptible of scientific determination and measurement. Their combination when obtained, while not giving the complete expression for car performance, still affords a valuable comparison for cars and constitutes what might well be called the "automobile performance factor." This factor equals SAE.

When considered from the standpoint of this automobile perform-

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ance factor, different cars can be definitely tested, a definite value for each item in the factor obtained, and relative performance quantitatively rated as regards speed range, acceleration and economy of fuel. This factor affords the engineer, the manufacturer and the buying public a ready and reliable means of comparison of car performance. An investigation of the three items that make up the complete factor leads at once to comparative values in the details of performance. Suppose we have two cars, the first with speed range of 10 to 50 m.p.h. accelerating from 10 to 50 m.p.h. in 30 sec., averaging 20 miles per gallon; the second with speed range of 5 to 65 m.p.h., accelerating from 5 to 65 m.p.h. in 20 sec., averaging 10 miles per gallon of fuel.

$$SAE = 40 \times 20 \times 2 = 1600 \qquad \text{(First car)}$$
$$SAE = 60 \times 10 \times 4.4 = 2640 \qquad \text{(Second car)}$$

This factor, or more properly the three items of the factor, when considered with C (riding comfort) afford an accurate estimate of complete performance or ability and should form a sound basis upon which to judge the car as an operating unit. Individually we can go even further, assign a relative percentage value to C, multiply the performance factor by it, and obtain at once a figure for each car that represents complete performance or ability. Some question may rightly be raised as to the relative weight that should be given S, A and E in the factor, but after extended consideration, it would seem that from the standpoint of importance to the operator, only equal weights can be assigned. The car weight does not appear separately in this factor, but indirectly exerts its influence upon S, A and E. In each case the penalty for increased weight appears in a reduction of the value of acceleration, mileage per gallon of fuel and speed range, the effect upon the final automobile performance factor being marked. It must be emphasized that the items in the performance factor have reference solely to performance of the car as it stands, as an operating unit.

The relative advantages of the seven seats of the touring car as compared with three in the roadster, the riding qualities of the heavy car as compared with the light car, the operation of the twelve-cylinder engine, as compared to the four, six or eight of equal horsepower, the advantages of the limousine as compared to the touring car—these are matters to be settled in a preliminary consideration or to be included with proper weight in the riding-comfort item C. The factor is of particular value in comparing the relative performance of two cars of similar characteristics. It is not desirable to compare, from the standpoint of performance, widely different structures, such as the pleasure car and the truck, vehicles designed for entirely different service, in which the various items that make up performance have entirely different relative values. The performance factor for the commercial truck can be quite different and is therefore a subject for separate consideration.

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DETERMINATION OF PERFORMANCE FACTORS

The actual conduct of tests necessary to determine speed range, acceleration and economy is not difficult. They should be run under the direction of a competent and disinterested judge or official who shall be responsible for and certify to all the tests and who shall have authority to appoint his assistants. In order to obtain uniform and comparable road conditions, all tests should be run upon a substantially level road surface or speedway of asphalt, brick, concrete or wood. The results of tests on such surfaces will be higher than average results that might be obtained in "ordinary service" by the owner, and in no way should they be represented as the latter. Cars tested should be strictly stock cars in every particular, carrying full complement of passengers and full standard equipment. In no case should the tests be run where there is appreciable wind, that is to say, wind over about 15 m.p.h. The complete test for performance includes at once the runs for determination of all three stated factors and in no case should change or adjustment of parts be permitted during the complete test (for example, carbureter adjustment, gear ratio, tires).

The test for determination of speed range hardly needs discussion. The lowest speed at which the car will operate steadily and continuously and from which with careful manipulation it will pick up through its range can be determined by successive trials. The test for steady operation at lowest speed should cover probably a mile, the actual determination of the speed in miles per hour being made by timing over a measured course. The maximum speed would be determined in a similar way.

The acceleration test should provide for measurement of the maximum acceleration of the car in feet per second per second, at a series of speeds covering the complete range. Approximate results have been obtained (1) by use of calibrated speedometer and stop-watch and (2) by use of calibrated speedometer and accelerometer. In the first case acceleration is determined by measuring the time necessary to accelerate between speeds equally above and below the given speed. For example, acceleration at 20 m.p.h. is determined by observing the time necessary to increase the speed from 15 to 25 m.p.h. In the second case an accelerometer is carried in the car. With the car running at any given speed, the throttle is opened wide and the acceleration reading taken direct from the accelerometer. Either of these is a simple and approximately correct method and as such has value. On account of inherent inaccuracies in the instruments, the lag and absence of dead-beat characteristics in both the speedometer and accelerometer and the personal equations that must play a considerable part, these methods would hardly be recommended for standard or certified tests.

A simple and accurate acceleration test has been proposed as fol-

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lows: The car is brought to its lowest successful operating speed and driven at that speed to the starting line of a measured course. It is then accelerated as rapidly as possible to its maximum speed. The course is marked off in equal divisions; at each division a contact point is located, which can be struck by a small gate carried under the front axle. At the starting line is located a recording drum, revolved by clock mechanism or by an electric motor driven by batteries. Writing its record upon this drum is a small marker, which is electrically operated by a calibrated clock and which registers time elapsed in seconds or half seconds. Another marker is electrically operated when the various contact points along the course are struck

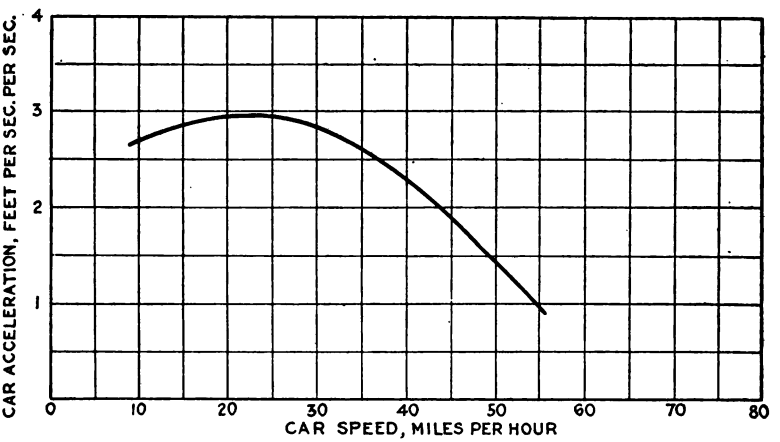

FIG. 1—ACCELERATION CURVE FOR SIX-CYLINDER CAR

by the gate under the front axle. Thus is obtained an accurate record of the time for traversing each of the measured intervals along the course. From these data, the accelerations at the different speeds can be determined accurately, either by means of curve plotting or by calculation. The final acceleration curve will show the acceleration in feet per second per second of the car over its complete speed range.

Fig. 1 shows an acceleration curve for a six-cylinder car, total weight 5280 lb., gear ratio 3 10/13 to 1, size of engine 4½ by 5½ in., wheel diameter 37 in. Fig. 2 shows an acceleration curve from an eight-cylinder car, estimated gross weight 4150 lb., gear ratio 5 1/14 to 1, size of engine 3⅛ by 5⅛ in., wheel diameter 36 in.

Fuel economy, or mileage per gallon of fuel must be determined by a series of runs at various speeds, as, for example, at five-mile intervals over its speed range, and a curve plotted showing miles per gallon as ordinates and speed of car in miles per hour as abscissas. Typical curves for fuel-economy runs are shown in Figs. 3 and 4.

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The curve in Fig. 3 was obtained from tests of an eight-cylinder car, 3⅛ by 5⅛-in. engine, gear ratio 4½ to 1, tires 36 by 4½ in.; estimated gross weight, 4150 lb. The curve shown in Fig. 4 was obtained from a test of a four-cylinder car, 3⅝ by 4½-in. engine, gear ratio 3.58 to 1, tires 30 by 3½ in., estimated gross weight 3000 lb.

Two methods for determining fuel economy are directly available; either with proper apparatus, proper care in manipulation and proper officials should prove accurate and satisfactory. The first involves the consumption of a gallon of fuel carried in a specially constructed tank, the supply from which can be properly fed to the fuel line at the starting point. The distance covered on the gallon is measured directly. The second method involves a run of say 10 miles at each

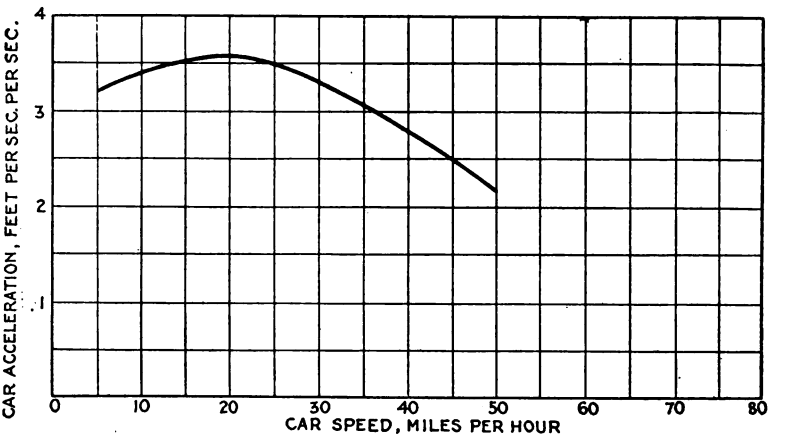

FIG. 2—ACCELERATION CURVE FOR EIGHT-CYLINDER CAR

speed, using fuel from a special tank. A pipe from this tank is opened into the fuel line at the starting point and closed at the finish, The weights of the tank at the start and end of the run are taken, and the mileage per gallon can then be determined. The second method is preferable, because it is more convenient and practical to conduct.

These determinations of speed range, acceleration and fuel economy are all parts of the performance test. They must be run as such, without change in car parts or adjustments. Any one of these runs, made by itself, with special adjustments or special parts, is of little value. If it is desired to compare two cars after test, the automobile performance factor is obtained by multiplying the speed range, the average acceleration over the entire speed range as determined from the acceleration curve and the average fuel economy in miles per gallon from the fuel-economy curve.

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OTHER PERFORMANCE OR ABILITY FORMULAS

Many formulas for automobile performance or car ability have been developed. They differ widely in the method of approaching the question and in the fundamental factors included; in the majority of cases they are efficiency formulas strictly, developed for estimating from engine size, gear ratio, weight and wheel size, the probable performance or probable performance factors of a car. In the opinion of the author none of them is as comprehensive as it should be. Not one is based entirely upon accurate scientific tests that determine the true values for the factors making up performance and therefore the

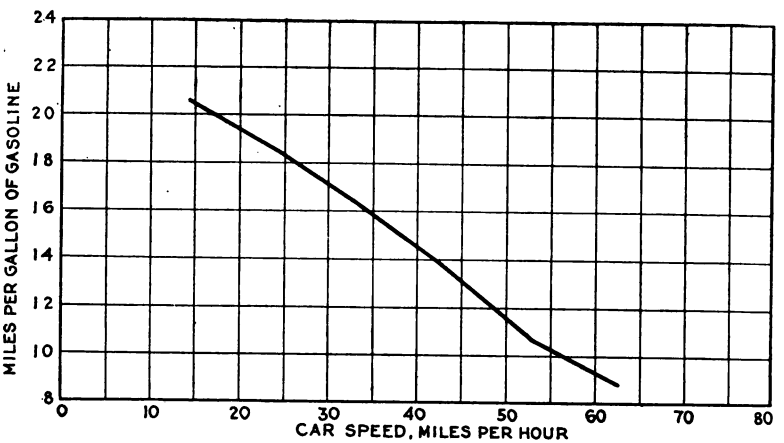

FIG. 3—FUEL-ECONOMY CURVE FOR EIGHT-CYLINDER CAR

true value for performance itself. The most important of these formulas will now be considered, using the following symbols: d = cylinder diameter, in.; S = stroke, in.; N = number of cylinders; R = gear ratio; D = wheel diameter, in.; W = vehicle gross weight, lb.; M = average fuel economy, miles per gallon; P = engine horsepower at given speed; D_p = excess drawbar pull at any speed over that necessary to propel the vehicle at that speed.

$$Ability = \frac{Pr}{WD} \tag{1}$$

This simple formula is one of the oldest and perhaps most widely known for estimating so-called ability. Its mathematical value has a direct physical interpretation, in that at a given speed for cars of equal transmission and rear-axle efficiencies, it will be proportional to total drawbar pull per pound of weight. For cars of different transmission and rear-axle efficiencies, the formula becomes inaccurate. Acceleration or hill-climbing ability of a certain car at a given speed is proportional, however, to excess drawbar pull per pound of weight

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over that necessary to propel the car at the given speed, so that even as an estimate of this one factor in automobile performance, the formula is hardly tenable. The total drawbar pull per pound of weight can be the same for two different cars, for example, a limousine and a roadster, yet the excess drawbar pull per pound of weight, and therefore acceleration and hill-climbing ability can be quite different, especially at comparatively high speeds. The mere substitution, as is customary, of maximum engine brake horsepower for P in this formula is of little if any value. If maximum torque were used, instead, we should come nearer to the relative hill-climbing and acceleration abilities, but even then the results would not be directly comparable. As a formula for estimating complete automobile

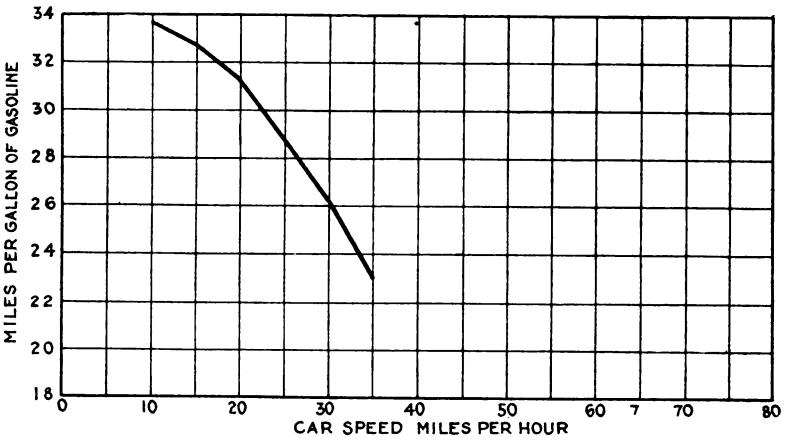

FIG. 4—FUEL-ECONOMY CURVE FOR FOUR-CYLINDER CAR

performance or ability, it does not include the three factors, speed range, fuel economy and riding comfort. As a formula for use to obtain the automobile performance factor it does not include speed range or fuel economy, and is not strictly correct for acceleration or hill-climbing ability.

$$\textit{Vehicle Coefficient} = \frac{8\,n\,d^2\,s\,r}{D\,W} \qquad \text{(Myers, 1915)} \quad (2)$$

$$K = 14{,}550\,\frac{d^2\,s\,n\,r}{D\,W} \qquad \text{(Roebuck, 1912)} \quad (3)$$

$$Q = 3000\,\frac{d^2\,s\,n\,r}{D\,W} \qquad \text{(Thomas)} \quad (4)$$

The close similarity of formulas (2), (3) and (4) is manifest. John Younger has pointed out that they represent piston displacement per pound moved 1 ft. On the assumption that every cubic inch of piston displacement represents so many foot-pounds of en-

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ergy, they give a measure of a car's ability. The greater the displacement per pound moved 1 ft., the greater should be the car's ability to speed, to climb and to accelerate on the particular gear reduction considered. From another viewpoint each of the three formulas represents total drawbar pull per pound of weight. These formulas may be of value in estimating total drawbar pull for cars of the same transmission and rear-axle efficiencies, providing the engine efficiencies are equal. Considered as formulas for acceleration or hill-climbing ability, practically the same difficulties appear as with (1). The constants in these formulas are the result of a number of assumptions, which in widely different cars do not hold. The constant 8 in formula (2), for example, is based on the assumption that all engines will develop a torque in pounds at 1-in. radius equivalent

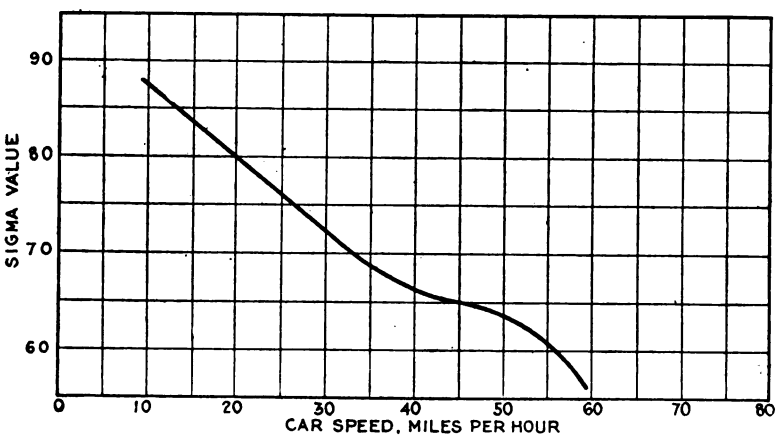

FIG. 5—SIGMA VALUES FOR SIX-CYLINDER CAR.

to that of their N. A. C. C. horsepower rating, and that the product of engine efficiency by transmission efficiency for the average well-built car will be about 95 per cent. Even aside from these assumptions, the formulas give merely an approximate estimate for total drawbar pull per pound of weight. In no way are speed range, fuel economy or riding comfort taken into account.

$$\Sigma = \frac{d^2\, s\, n\, r\, M}{10\, D} \qquad \text{(Thomas, 1913)} \quad (5)$$

The so-called Sigma formula differs from the others considered in that the factor M (average gasoline consumption, miles per gallon) is included. This is determined by complete tests and is evidently a proper and reliable factor in performance. The remainder of the

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formula ($d^2 s n r/D$) represents piston displacement per foot the entire car is moved; from another viewpoint it represents approximate total drawbar pull. Acceleration or hill-climbing ability is in no way proportional to total drawbar pull, no matter what the weight and the drawbar pull necessary to propel the car at any given speed. The difficulties encountered with this part of formula (5) are therefore as serious as, and even more so than, those for formula (1). Only in cars with the same engine, transmission and rear-axle efficiencies will a formula based on engine dimensions, gear ratio and wheel diameter give a reliable approximation for total drawbar pull. Total drawbar pull is not in general a measure of the acceleration or hill-climbing abilities of the foregoing cars. No account is taken of speed range in this formula. The curve in Fig. 5 was obtained by plotting the values of Sigma for a six-cylinder car, bore and stroke 5 by 7 in., gear ratio 2.88 to 1, wheel diameter 38 in., estimated total weight 5900 lb.

$$Ability = \frac{D_p}{W} \qquad \text{(Brush, 1916)} \quad (6)$$

This formula, which represents excess drawbar pull per pound of weight, gives an accurate measure of hill-climbing ability and an approximate measure of acceleration. It has been proposed that the excess drawbar pull at any speed be determined directly by test upon a level course or speedway, a special dynamometer car to be attached to the rear of the car under test and the speed controlled by brakes on the special car. If such a special dynamometer car can be devised, and if the dynamometer under the conditions of high speed incident to such tests would give substantially steady and accurate readings, this method would be direct and acceptable for the determination of that one item, excess drawbar pull, which in automobile performance is evidenced by hill-climbing ability, acceleration or by both. As a complete automobile performance or ability factor, this formula takes no account of fuel economy or of speed range. It is suggested that the value of (6) be multiplied by E and then by S, for the complete factor. If the proposed tests of the drawbar pull can be successfully carried out, this complete factor would seem to be satisfactory.

AUTHOR'S CONCLUSION

The matter of automobile performance is not new. Much has been written and argued thereon. The demand is world-wide for a standard interpretation for performance and a method of determining it. Numerous formulas have been proposed. In most cases these are efficiency formulas, designed for estimating from certain known dimensions the probable performance or performances factors. In no case are all those factors included that seem critical in performance; in

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several cases serious inaccuracies can be pointed out when their application to actual road performance is attempted.

Automobile performance should be determined by actual tests. Speed range, acceleration, fuel economy and riding comfort are proper and sufficient factors for such determination. The first three of these factors are susceptible of measurement by accurate scientific tests. An accurate and scientific performance factor would result from the following combination of the results of such tests:

Automobile Performance Factor = *SAE*

At best the problem of what to do about the performances of automobiles is a difficult one, worthy of careful and cooperative effort. In closing I can agree with each of two men to whom the question of automobile performance was broached. One was a chief engineer, experienced and conservative. "Why, man," he said, "it is almost as hard to tell what you mean by first-class ability in an automobile as it is to design one that will have it." The other was an old negro farmer, prosperous enough to have replaced his mule with a modern-self-starting automobile. "Poor-formance," he drawled, when approached on the subject, "she am jest as pesky as ma ole mule, an' thar's faah more things to get out ob disorder."

DISCUSSION

ACTING CHAIRMAN CORNELIUS T. MYERS:—Professor Fishleigh has accurately analyzed performance formulas given by others, although so far as those given by Mr. Thomas, Mr. Roebuck and myself are concerned, there is no attempt to recommend them as measurements of efficiency. They indicate a probable result and are used as methods of comparison and in making new designs.

I believe that the factor of speed range is open to argument—particularly as to whether it should be included in the manner recommended by Professor Fishleigh. Take two cars with speed ranges of 10 to 40 and 5 to 65 m.p.h. According to Professor Fishleigh, the performance of the second (60) would be twice that of the first (30). Looking at this from another viewpoint the 40 is four times the lower speed limit, whereas the other (65) is thirteen times the lower limit. One is over three times as great as the other. It is just as logical to look at it in the way I have proposed as in any other, because as the speed is decreased the difficulty in obtaining satisfactory operation is increased. If the speed range is an essential factor, which should be considered in direct proportion, the ratio of the high to low speeds should certainly be used.

K. W. ZIMMERSCHIED:—A high tribute is due Professor Fishleigh for his analysis of this question. We must admire him for proposing

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so simple a solution, because he knows how diverse and fixed are the views of engineers in this connection; he therefore must have expected to stir up a violent discussion.

He has given, for two cars, the multiplication of three items and by inference, at least, the product of those items is called the performance factor, for a certain car. We might take another case: 60 × 4.2 × 10 gives a product of 2520; and for another car 50 × 2.5 × 20, which would not be unreasonable, gives a product of 2500. The products are practically the same for the two cars, indicating that they would give equal performances, whereas we know that the performance of the two is vastly different, one having only an acceleration of 2.5, and the other 4.2 ft. per second per second. I believe the *product* of these items should not be considered at all.

I propose that, instead of considering a product at all, we consider only the separate enumeration of the items. Taking the case of the first car cited, we would say that it has an ability of 60 × 4.2 × 10. But even now we have not obtained the final answer, because the 60 might be the difference between any two figures, so that it does not indicate specifically where the speed range lies. The 4.4 is acceleration in feet per second per second, a unit that the ordinary man does not understand and that many engineers fail to appreciate. The 10 indicates miles per gallon over the whole range, which is a difficult value to obtain.

Let us use specific expressions for these items, in terms that all can understand. Instead of 60, let us say 5 to 65; these are the actual limits of the speed range of the car. Let us quote acceleration by giving the lowest operating speed followed by the speed in miles per hour to which the car will accelerate in say 10 seconds, thus: 5 — 30. I would quote fuel consumption at average city driving speed and at average touring speed; say in miles per gallon at 15 and at 30 miles per hour, thus: 12 —10. The whole expression for the items *S*, *A* and E therefore becomes 5 — 65 × 5 — 30 × 12 — 10.

We might consider these to be the three dimensions of car performance. Professor Fishleigh has also added the item *C*, which we will have to treat as the elusive fourth dimension, indeterminate, intangible and inconceivable.

FORMULA SHOULD BE UNDERSTOOD BY USERS

A. P. BRUSH:—If the Society adopts a standard for car performance that will enable the manufacturer to tell Mr. and Mrs. Average User what the performance value of his car is, accurately and understandably, the Society will have contributed to the industry that it represents. If, on the other hand, it recommends a car-performance formula that is not understandable, that is not exact, and that can be either intentionally or inadvertently used to deceive Mr. and Mrs. Average User, then the Society will not have done itself credit.

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I believe that there are a great many objections to the method proposed for the expression of car performance. Take, for example, the question of fuel consumption, or, as expressed, of miles of travel per gallon of fuel. Is that a factor of car performance? It really is the cost, in fuel, of securing that car performance which that particular car gives. The first cost of the car and the cost of its maintenance are also factors in determining the cost of securing that grade of performance which that car is capable of giving; therefore, first cost and repairs, garage charges and all that go to make up maintenance are just as properly factors of car performance as is fuel economy.

Take the question of speed range,—and bear in mind that this is for Mr. and Mrs. Average User; let us take a hypothetical range, 4 to 60 m.p.h. That range will please Mr. and Mrs. Average User; but with the method proposed, to take an extreme example, a car with a speed range of from 44 to 100 m.p.h. has the same value. I wonder how Mrs. Conservative Driver would feel if she bought a car that showed up well on a statement of values as expressed by this formula, but found that 44 m.p.h. was as slow as she could run it on high gear. Mr. Myers' suggested modification is open to the same exception, in a lesser degree. He says, take the ratio of high to low speed; then 10 to 40 has the same value as 20 to 80 m.p.h. The average automobile driver would hardly be satisfied with a car that would not run less than 20 m.p.h. on high gear. We are producing high-speed engines, multicylinder engines, in order to give the user cars that will travel not only at a satisfactory high rate of speed, but also will come down to a satisfactory low rate of speed. Of the two, the low rate of speed is of most importance to the average user all the time; it is of most importance to the exceptional user most of the time. If speed range is to be a factor in car performance, some differential value should be given it.

TESTING WITH DYNAMOMETER

The dynamometer has long been used for testing. Prof. Fishleigh, in his paper, says that it takes no account of fuel economy or of speed range. On the contrary, I believe that the dynamometer makes possible the taking of exact account of speed range and fuel economy, in a way that the proposed method does not and cannot do. Prof. Fishleigh mentions the lowest speed at which the engine will operate smoothly. Does he mean the lowest speed at which the engine will operate smoothly, carrying 1 or 100 per cent of its load? I think we must call the lowest speed at which the car will perform that minimum speed at which the engine will perform smoothly with the throttle wide open. A car can, under light load, on a level road, roll along smoothly at 2 or 3 m.p.h.; but on a hill or a heavy road its performance can be intolerable at those speeds.

With the dynamometer it is possible to determine fuel consumption

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under as many conditions of load as desired, below the maximum and at the maximum. If fuel economy is to be considered at all, the public is entitled to know the fuel consumption when the car is doing all it can. Therefore we need a method of determining how much fuel it will take to produce the maximum results.

It is also only fair to the car to make at least one other fuel economy determination, which the dynamometer method makes practicable. The D_p/W value expresses directly the size value of that hill which the car can climb, or which it is climbing during the test. We can therefore assume the average driving conditions are equivalent to let us say a 1, 2 or 3 per cent grade, and make fuel economy tests at as many speeds as we please; we will then have a reasonable indication of what mileage that car will give at the various speeds, driving under average road conditions.

I must take exception to one other thing in this proposed method of Prof. Fishleigh's; that is the giving of a value to averages. Take any of the acceleration curves and assume that the curve be reversed. The high acceleration being at the high speeds, and the low acceleration at low speeds, that car will not do as satisfactory work, or be as satisfactory to the average driver as the car with a higher acceleration at low speeds, and lower acceleration at high speeds; yet the average is the same, although the performance will be, to say the least, startlingly different.

ACTING CHAIRMAN MYERS:—I believe that in the discussion we need not consider that this formula must be suitable for the use of Mr. and Mrs. Average User. If we can develop a formula that can be used by everybody, so much the better; still, we are not at all obligated to develop such a formula. We must develop the right formula, and the one that will serve the engineers the best; they are building these cars and will be held accountable for them. We want to be able to check results, and we want to be able to show those to whom we sell these cars that there is a comparative value, but in developing a thing of this sort we should not compromise it in any form simply to make it understandable, or possibly more understandable, to the average automobile user.

REASON FOR FINDING PERFORMANCE

J. B. REPLOGLE:—What will be done with this formula? What is its purpose? It seems to me that these questions will have to be answered first. Is the acceleration or hill-climbing ability of a car, and nothing else, to be labeled car performance, so that we can hand it over to the selling department to talk to Mr. and Mrs. Average User about under a different name that he will not understand; or are we going to develop something that will represent car performance and that will mean something besides hill-climbing or acceleration? The whole question seems to come down to a matter of definition

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and units. The solution of the whole problem is: First, make a decision as to what is to be done with the formula; then select units that any one can apply rationally.

If I buy a car, I am buying the one thing that I can buy with money, and that is experience. If my car performance shows me what I will get in the way of experience for my money, then the item C (riding comfort) will have to be taken into consideration, because I am interested not only in the acceleration or hill-climbing value, the speed range and the fuel economy, but also to know whether somebody will hear me coming when I am a half mile away; whether I will have my toes tickled so that I must stop and scratch them if I run over 30 m.p.h. It will be necessary to assume certain values for noise, for vibration and for endurance of the car, however arbitrary and empirical these units may be.

W. B. STOUT:—I think that it would not be proper for the Society to settle on a formula based entirely on the factors ($S\ A\ E$) mentioned, when the C factor is possibly the most important of all, even if it is more or less indeterminate. There are so many factors in a car that are psychological—that give what we call impression. Nothing in the formula as proposed shows the outsider the difference between one make of car and another, such as he would get when he saw the car or rode in it. The factors named would give a certain figure, but the public, knowing that this Society represents supposedly the best brains in the industry, would be likely, if we said that the car that has the highest figure is the best car, or even implied it, to take the formula as a cure-all, to the detriment of cars that have more of value than just these three factors.

MODIFIED PERFORMANCE FORMULA

C. C. HINKLEY:—These cars are certainly designed around a formula. I do not see why we cannot have this formula for design involved in the formulas that we give the public as actually demonstrating what the cars shall do. Some time ago the Franklin Company brought out a formula that shows a great many things. I have modified it, and I will give you my modification. Divide the product of displacement in cubic inches and gear ratio by the weight times the wheel diameter. Now, if it is desired to introduce other factors, let us set a standard test of from 5 to 50 m.p.h. Any car ought to do that say in time t. Then

$$\text{Ability} = \frac{Dist \times GR}{Wt \times WD \times t}$$

The quicker the acceleration from 5 to 50, the greater the ability. I have designed model after model on that formula, and it actually works. Any car performance can be duplicated by its application.

V. R. HEFTLER:—I agree with Mr. Zimmerschied, who wants to use three different factors. In buying an electric motor or trans-

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former we know the size and kind of transformer and then decide on it from a set of efficiency curves, power factor curve, etc. Why not take just a step further than Mr. Zimmerschied proposes, and give similar curves for the car performance? They may not be understandable to the general public, but that might not be a great objection.

I believe that the economy test, which is outlined in the paper, should embody some way of showing the physical condition of the car. If a car is limbered up well, all the bearings are loose, everything free, and the oil not too thick, the rolling resistance is much smaller than the rolling resistance of a stock car, if there is any such thing. The difference is shown at once by the fuel economy. How will that fuel economy be determined, unless it includes the value of the rolling resistance of the car, which could be checked afterward on a car that does not give good economy. If the formula for performance does not need to be understood by the public I recommend the use of one of the formulas already available; I believe they can easily be made understandable. They are all based on measurements—not measurements of performance or acceleration, but on measurements of length, bore, diameter, strength, gear ratio and weight.

It is almost impossible to devise a formula for car performance. In such a formula we would have car performance expressed as a function of various variables, which can be geometrical quantities or quantities determined by experiments conducted under certain rules; if the values thus found are substituted for the variables in this hypothetical formula, the result is a number which cannot but be absolutely meaningless and useless as a guide for the public.

It is about as difficult to advise regarding the purchase of an automobile as regarding the purchase of stocks. The financial papers say that in stocks there are the factors—safety, income, marketability; according to the buyer's position, and what he wants to do with his money, he gives the preference to safety, income or marketability. The same thing is true of performance; according to what is desired of the car, preference is given range of speed, economy, weight or comfort.

LOW RANGE OF SPEED

E. PLANCHE:—In order to be more precise I suggest that we make the automobile-performance formula equal SAE/L, in which L will be the lowest speed that can be maintained on high gear, with the car running smoothly.

I have been making some tests on cars to determine the relative value of different types of carbureters. All my tests have been made along the lines of speed range, acceleration, and economy of fuel. The only variation I had from Professor Fishleigh's methods was to make the economy test on the same road both ways, to take care of the wind factor and to make ten to twelve tests to strike a good average.

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It would also be well to state whether the top is up or down, whether the windshield is closed or partly open. In comparing the performance of different cars, the road conditions and the atmospheric conditions should be the same, for the friction between wheels and the ground decreases in wet weather.

O. E. HUNT:—I certainly sympathize with Mr. Replogle in his question, as to what we are after, and what we are going to do with it when we get it. We can agree that car value is made up of such factors as reliability, style or appearance, comfort and performance. The sum total of these things represents value to the ultimate consumer. The discussion has ranged pretty well over the subject of car value, instead of being confined to car performance, which Professor Fishleigh has defined as being limited to speed range, acceleration, economy and riding comfort. Some exceptions have been taken to his definition. It seems to me that we, as engineers, in endeavoring to establish a measure of performance, are interested in characteristics that can be scientifically measured. I believe that the proper definition to give a performance factor expressing total car value is to say that such items of car performance as are important to the average owner and are capable of accurate scientific determination and mathematical expression should be included in it.

Our consideration of speed range must be limited to the speed ranges that will interest the public. It is not difficult to set the lower end of that range, because the average user would like to have his car go about zero miles a minute, sometimes, in traffic, without shifting gears. The high-speed end of the scale, that is, the high-speed limit, is determined for us by American road conditions. It is safe to assume that the average will not exceed 60 m.p.h. It might be well to make it lower, but suppose we take that as a basis. A half a dozen cars will do 60 miles all right, but they have different low-speed characteristics. Let us assume that one will do 6, one 4 and one 2 m.p.h. The fair way would be to divide this high-speed characteristic, or the high speed that the public is interested in, by the lowest satisfactory low-speed performance of the car, and let that stand for the first element in the performance factor. There does not seem to be much question about the desirability of including acceleration measured by some standard method and the economy factor as well. It would be well if we can establish a performance formula that will be useful to engineers, based on tests that can be duplicated, if necessary, by the average user who wants to compare the performance of the cars that are offered to him.

PROPER PERFORMANCE FACTORS

C. C. HINKLEY:—We ought to reduce performance to mathematics. In the formula that I gave, the performance varies directly with the piston displacement. The performance will increase with the displacement and as the gear ratio is reduced. It will vary with the

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weight; it will decrease as the weight is increased. It will decrease as the wheel diameter is increased. By taking a combination of the product of the first two factors and dividing it by the product of the second two, a result will be obtained that shows just what the engine will do in connection with the car. The weight factor ought to be based on the car weight plus the passenger load, which, in my work, is about 3600 lb. Let us set an arbitrary speed range of 5 to 50 m.p.h., the latter being about all that American road conditions will stand. Under no circumstances should the limit be set above 50 m.p.h., as I believe that is about the safe maximum driving speed we can guarantee under these conditions. Take a factor of 5 to 50 m.p.h. and a time limit in that speed range of 30 sec., or 25 sec. It is easy to divide performance results by time in seconds, and put it in black and white, and reproduce any performance.

ENGINE POWER VARIATION

A MEMBER:—In the past five years engines have varied in maximum power from 0.11 to 0.22 hp. per cu. in. of displacement; and from 0.4 to 0.7 ft. lb. torque per cu. in., so we can hardly use displacement in the matter of performance.

C. C. HINKLEY:—Modern motor-car design, so far as efficiency goes, has not varied much lately. A well-designed L-head engine will give 0.19 to 0.22 hp. per cu. in. of piston displacement.. A valve-in-the-head engine of good design, from 0.22 to 0.27 hp. per cu. in., so that the difference in power performance must be one of the factors left for the sales department. If we should accept 0.22 hp. per cu. in., the formula that I have suggested will give fairly close to the desired results.

J. B. REPLOGLE:—Mr. Hinkley's formula can be used as an expression of acceleration efficiency. That is, the displacement multiplied by gear ratio, and divided by wheel diameter times weight, is an expression of what the machine should do in the way of acceleration. That result divided into what the machine actually does in the way of acceleraton gives acceleration efficiency. If acceleration efficiency is what is wanted in car performance, the formula is satisfactory. After all, it is a question of what we desire to know about car performance. Is it economy, or range of speed, or what? If the Society wishes to state that car performance shall be synonymous with acceleration efficiency, then I agree with Mr. Hinkley. But if car performance is to include all the desirable factors, then we must apply arbitrary values, if necessary, to all the things that go to satisfy the person who is driving the car, so that he gets his money's worth in pleasure.

JUDGING FROM MANY STANDPOINTS

C. ROY WATSON:—I think the public is interested in actual performance of the car from broad standpoints, perhaps from fifty different considerations. If we take an article to a fair or exposition,

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expert and impartial judges look at it from many standpoints and draw conclusions. All these factors given in the designer's formula can be considered in the judging and comparative conclusions drawn. We can put those conclusions together, let each represent a certain percentage, and add them. One car will be better than another, in some details, which will be assigned a certain percentage. The best car will be awarded a gold medal, the next best perhaps a silver medal, and so on down the line. I think such a method of estimating car performance would be the best way of doing it for the benefit of the public.

Formulas given on the basis of measurements are misleading in actual value. Two engines and cars of the same weight and measurements may give entirely different results on the road. One very potent point in Professor Fishleigh's ideas should not be overlooked. He mentions at length the personal factors, and other things to be considered in making the tests on the road. Let us adhere to actual performance. Do not try to give the public measurements and formulas; give them actual performance in terms that they can understand.

ACTING CHAIRMAN MYERS:—We can elaborate this performance formula but even then we have no assurance that the public will adopt it. What the paper has placed before us is a commendable suggestion, one that, so far as two of its factors are concerned, is understandable by the public. The minute however we consider anything that cannot be applied mathematically we shall get into trouble.

The two factors, acceleration and economy of fuel, are determinable. I believe that both of them should be given. The minute we multiply acceleration by economy and divide that by the diameter of the tire the result obtained is not easily understood and it can be warped.

The application to acceleration of the formula suggested by Mr. Hinkley is a simple matter. It was used as a design formula but there is no reason why it could not be used as a formula for actual comparison. All that is necessary is to take the actual dimensions, multiply them together and obtain a theoretical result, then by the use of an accelerometer, or of a stop-watch and correct measuring device, the actual performance of the car is obtained. The latter divided by the former gives a result proportional to the theoretical efficiency.

SCIENTIFIC METHODS NEEDED

A. P. BRUSH:—A car-performance formula should serve a purpose similar to the interstate-commerce law, that requires a sealed package shall bear a guarantee of its net weight. That one package guarantees more net weight than another is no reason why one should change his desire for pickles and buy peaches. The average buyer of a car can determine many of the things that appeal to him about the car,

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from the exercise of his five senses. As Mr. Stout pointed out, the senses of the average man and of the engineer can be deceived readily about certain things in performance. It is essential that those characteristics that cannot be perceived accurately by our senses unassisted should be measured accurately, if we are to know what we have in the car.

Certain formulas mentioned are excellent for the designer who has started to lay down a car; but when he has done that, and built the car, we want to know whether we have what we started out to have. Further than that, when the car is put into production, as engineers we need some method of determining whether the manufacturer is duplicating the results that the design was intended to secure; for that reason we need a scientific method of measuring those characteristics of car performance that cannot be perceived readily by the senses.

E. V. RIPPINGILLE:—I appreciate that engineers should have some method of comparing car against car, but I really do not see how a formula can be evolved that will give a result really meaning anything. We must consider each factor individually, because cars are built and marketed on individuality.

For comparative purposes, no doubt, a formula would have some value. But take acceleration, for instance. We talk of the relative values of 5 to 65 and 5 to 50 m.p.h.. There is no question but that 65 m.p.h. is seldom used, but nevertheless acceleration ability over such a range means considerable difference in the car performance.

Another thing that must be considered is, what would happen to some of these cars that accelerate from 5 to 65 m.p.h. so quickly, because of their low gear-ratio and high engine-speed, if we kept them at 65 m.p.h. for a little while? Does not reliability count for more, in the public mind, than the extra 5 m.p.h. that makes them unreliable? The public appreciates that a car that will go through the greater speed range with less danger when maintained at high speed is one with a greater factor of safety from the user's standpoint and as far as repairs and maintenance are concerned, than a car that will go through a similar range with less reliability. Performance of any kind, whether it is acceleration, comfort, economy or anything else, must be really constant to be of any value. Spontaneous performance does not lead to any good results. Professor Fishleigh's formula tends to place a value upon spontaneous performance, and does not sufficiently include the most vital factor—reliability.

I do not know how to express car performance. I rather pride myself on being a judge of automobiles, yet all I can tell of them is based on personal opinion. Reliability, safety, ease of control count for more, in my opinion, than a few miles of speed and a little greater range of accelerative ability, and I think the public feels that way about it.

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AUTHOR'S CLOSURE

PROF. W. T. FISHLEIGH:—My proposal, which I think is fairly generally agreed to, is first, that acceleration has something to do with performance. Fuel economy is important in car performance, when it is considered as an efficiency factor. Fuel economy is different from garage expense in that it is a measure of the work done with so much gasoline in a certain design of car, and is dependent upon efficiencies of engine, transmission, rear axle and tires. Other things being equal, if one car travels 20 miles on a gallon, and another 18 miles, the one is certainly, from the engineer's standpoint and the standpoint of the public, a car of better efficiency or better performance. I started out with a formula with low speed as one of the factors. But after I talked with half a dozen friends I decided that I had over-emphasized low speed, so I simply used the speed range. The product of the three factors (*SAE*) does not in itself mean anything. My proposal is simply this: Measure acceleration, fuel economy and speed range on the road. Do not estimate them. Estimates are all right in the engineering department to anticipate performance as well as may be when a car is being designed. Then anyone can look at the three factors and can make a definite estimate of performance as he values it. I do not believe there is much to be gained in multiplying the factors together, but I believe we agree that those three factors are important. I submit that judgment of performance can be based on these three.

If we have psychological purchasers or psychological engineers who wish to buy a car on account of the name of the maker, let them buy it. They do not want to study performance as such. If a man buys a car because of its name, just as he might buy a piano, purely for the name and regardless of price, quality or performance, what does he want with the performance factor or with performance figures? Nothing at all. I have advocated, not the taking of average figures, but always the giving of complete curves. The complete curves give the whole story.

I included appearance and reliability in that comfort factor. If a man comes into the sales department and asserts that the matter of comfort, or the factors contained in the comfort factor, are more important than acceleration and fuel economy, sell him a car from the standpoint of the comfort factor alone, but do not tell us that the performance factor is wrong.

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CHASSIS LUBRICATION

By Roland Chilton

(Member of the Society)

At its inception the automobile was regarded as a horseless carriage, the horse being replaced by a mechanical prime mover and transmission gear. Engineering attention has naturally been mostly concentrated on these last units, as they represent the radical development involved in the automobile, the vehicular parts of which were already established by the coach-builders, whose traditions they have not yet wholly escaped.

As the weight and running speeds increased, the necessity for inclosing and providing continuous lubrication for the engine and transmission parts has been recognized and acted upon. In the case of the chassis parts however this development has been much slower, which is largely due to the fact that while an automobile with a seizure in the engine or transmission will not operate at all, yet it will and often does run with most of the spring joints and other chassis parts rusted or worn loose, with the familiar squeaks and rattles, harshness in the suspension and stiffness in the steering. A great deal of the labor necessary to maintain the average automobile in running order is that expended in the endeavor to keep the chassis parts lubricated by way of the conventional grease-cups and oil-holes. The elimination of the necessity for this very dirty job provides a powerful sales argument, and hence the interest which the subject has aroused.

CAUSES OF WEAR

Adequate provision for the lubrication of a bearing is quite useless unless the entrance of dirt and water is prevented. With a liberal supply of road grit in a bearing (the usual condition of most chassis parts at present) its destruction is rather facilitated than otherwise by the presence of a lubricant. Water causes rusting of steel surfaces, which aggravates wear, often causes complete seizure of a plain bearing, and will ultimately entirely destroy a ball bearing. Thus the protection from the bombardment of mud and water to which most chassis parts are subjected is of paramount importance in the case of lubricated bearings.

Another source of wear which no amount of lubrication can prevent is that arising from the impact on a joint due to vibration of the parts it connects. Brake rods and steering joints suffer greatly in this respect, because the long rods which they support are apt to develop periodic vibrations, which often have the effect of literally pounding away the pins and bushings. To make the joints large enough to stand this punishment usually involves too bulky a job. A more scientific solution is to impose an initial load between the joint sur-

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faces by means of a spring strong enough to prevent the surfaces separating under vibration, and so prevent the development of impact loads. When this is done in a ball-type steering-joint, for example, a small bearing surface will give good service, when a comparatively large surface in the "free" type of joint will rapidly pound away.

Mal-alignment in bearings is another source of wear outside the province of lubrication. For example: the pin joint at the axle end of a cantilever spring can be pulled several degrees out of alignment when one wheel is lifted, and the action of the spring draws that side of the axle forward or back. In such cases, and when chassis or other deflection can throw the bearings out of line, a self-aligning feature must be utilized or no amount of lubrication will avoid the binding and wear of the parts.

OILLESS OR IMPREGNATED BEARINGS

Metal surfaces subject to continued sliding contact under pressure, will abrade when dry, but it appears that this is not the case when the surfaces are of metal bearing on suitably prepared asbestos, wood, graphite, leather, paper, cotton fabric, fiber, celluloid, camel hair, mica, soapstone, jewels, and other non-metallic substances. These materials are being used for bearings in various mechanisms where oil is not permissible or difficult to provide for, and oilless or impregnated bushings using one of the first three materials are already in commercial use in the automobile industry. For cases when it is essential to have the least possible friction, or when high speeds would result in excessive heat, such bushings are out of the question, but this does not affect their usefulness in most of the bearings of the chassis mechanism of an automobile. Such bushings have already been used with success in spring eyes, for brake shaft bearings, clutch pilot or thimble bearings, clutch draw collars, gearshift shafts, steering shafts and cooling fans.

Spring inserts have been developed to meet the special case of sliding contact occurring in laminated springs. Engineers are not agreed as to the amount of friction desirable here, but all concede that this friction should remain constant throughout the life of the spring. The enormous increase in friction, which is caused by rust and which results when the ordinary springs are not kept continuously greased, is a well known cause of the harshness in suspension of many cars.

Possibly the severest case of sliding friction under load that occurs in automobile practice is that of the clutch. Considering the extraordinary durability of the bonded asbestos materials when used against hard steel plates for this very severe duty, the author expects to see great developments in the use of asbestos compounds for bushings. There are numerous examples of single-plate clutches using this material where the wear after continual service can scarcely be measured, the effects of the sliding being merely to put a glass-like polish on the surface of the hard steel and the asbestos fabric.

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Data as to the bearing pressure that can be safely used on the various types of oilless bushings are not yet complete, but their application as spring-eye bushings working on the standard-size pins is already reported to be successful. Intermittent reciprocating movement often causes difficulties in lubricated bearings, probably because the oil gets squeezed out when the parts are at rest, and the slight subsequent movements are insufficient to draw a film in between the surfaces again. Oilless bushings do not appear to suffer from this disability, nor are they so susceptible to the effects of dirt as are oiled metallic bearings. The bonded asbestos bushings, being more yielding than the metallic ones, do not have their surfaces pounded away so readily under the shocks due to the vibration, provided they are backed up by suitable containers to prevent the material spreading. Such bushings also appear to be free from any tendency to set up "squeaks."

The so-called chassis lubrication problem can be further avoided in the case of reciprocating movements by employing a flexible member that will permit the necessary movement without sliding contact. An automobile road spring is an example where such a member is used to guide an axle through several inches of travel, a function for which axle-box guides are used in railway rolling stock. An extremely difficult lubrication problem is here avoided in the case of the automobile. The flexible type of universal joint affords a further example. Ball bearings also carry out this idea, as with proper lubricant retainers and adequate capacity in the housing these will run for long periods without attention. This explains their use in many cases where their low frictional characteristics are of little benefit.

MAIN SOLUTIONS OF LUBRICATION PROBLEMS

There are thus two main lines along which the problem under discussion can be tackled: either we can work in the direction of automatic lubrication with metallic bearings, or we can develop the various oilless types of contruction. In each case our object is to increase the durability of the bearings, and to render them as independent as possible of the attention required for lubrication, adjustment and replacement.

Referring now to the "lubrication" method of obtaining these objects, we find that the first steps were made by substituting for the conventional grease cup a reservoir of large capacity, and arranging for oil contained in this to be slowly fed to the bearings. Steering-rod joints can be conveniently served by this method, the steering tubes being filled with oil and communicating with the surface of the steering ball by way of a hole. In order to minimize the rate at which oil is passed, the joint must be so designed that there is always a pressure between the surfaces at the point where this feed hole is drilled. The sliding of the surfaces as the joint works is relied upon to draw in sufficient oil to maintain a film, while the surging of the oil in the tube insures that it reaches the joints at either end. One reservoir

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can of course feed a large number of points, but in order to decrease the oil consumption the feed hole must always be drilled on the loaded side of the bearing, when adequate lubrication during many months of running can be obtained through one filling of the reservoir.

The necessity for this last operation can be avoided by coupling the parts concerned to the engine lubrication system in such a way that the driver can occasionally pass a small quantity of oil by opening a valve normally held closed by a spring. This method has already been used to replenish the steering box and to supply oil to the torque-rod head and other points. To obtain complete automaticity, together with low oil consumption, the problem to be solved is that of positively delivering minute quantities of oil to the various parts. One method of doing this is to convey to the rest of the chassis parts the "weepage" from one or more of the principal bearings, that are fed directly from the engine lubrication system. If the oil lead in these metering bearings is taken to a point that is always under load, oil will only weep through when the bearing moves, and the quantity can be regulated by adjusting the distance along which the oil has to creep between the bearing surfaces.

USE OF SURPLUS OIL

In the interests of economy it will be possible in some designs to arrange the lubrication of parts in series, the surplus oil from one point being conveyed to the next, and further, any surplus at the end of the system can be drained into the back-axle or gear-box casings.

An alternative system would be one in which the oil was positively circulated through the various bearings and returned to the engine pump. This however involves extremely efficient oil retainers at every point. As a further alternative a small plunger pump operated by a trip gear through a large reduction train—such as that employed in a mileage recorder—could be utilized to positively deliver oil, say once every 50,000 engine revolutions. A pressure drip-feed might also be employed, but no system involving the flow of oil through long pipes by gravity is permissible, a positive feed being essential to prevent stoppage.

The fact that most drivers will not fill grease cups continually and the frequent renewals necessary with unprotected metallic bearings have naturally been forcibly impressed upon garage and repair men, and the impulse for improvement has come largely from them. The first extensive scheme for overcoming these defects by the lubrication method was the conception of J. B. Ferguson of Belfast, Ireland, with whom the author was associated in the design of a car to embody this feature.

FERGUS LUBRICATION SYSTEM

The particular methods employed in this car are here briefly described by way of exemplifying the problems involved in the lubrica-

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tion of the various chassis parts. In general this chassis was designed throughout to facilitate and simplify the inclosure and lubrication of the working surfaces. In cases where the conventional construction did not lend itself to these objects, alternative constructions were developed that could be rendered oil-tight in a simple manner.

The basis of this system is an oil circulation pipe that runs from the engine oil-pump and delivers freely to the oil sump. This pipe connects to the hollow trunnion pins at the center of the four cantilever springs of the car. This is the only oil line in the entire system, and the oil pressure at the spring fulcrum pins is merely that due to the resistance the line offers to the flow of oil. This pressure is determined by the relative size of the pipe line and of the delivery hole from the pump. It should be noted however that in the event of a tendency to stoppage in this pipe the full pump pressure is available to clear the obstruction. An oil hole is drilled through the bottom wall of each of these spring fulcrum pins, that is, at the point where the load on the chassis always exerts a pressure between the bearing bushing and the pin.

The minute quantity of oil that weeps through between the pin and bushing under the influence of sliding action is used to lubricate all the rest of the chassis parts. In order to lubricate the bearings at each end of the springs, this oil is led through grooves between the spring leaves and from there to the other working parts. Thus, from the rear end of the front spring the pedal bearings are oiled. From the front end of the front spring the front-axle radius-rod joints are supplied. From the front end of the rear spring the brake cross-shaft bearings receive their supply, and any surplus oil from the rear end of the rear springs serves the brake camshaft bearings. All the spring joint housings are provided with lips, around which the ends of leather gaiters that inclose the springs are clipped. The spring joint housings are so designed that the working parts are entirely inclosed when the gaiters are in position.

STEERING TUBES ARE GREASE RESERVOIRS

The front hub has a large grease-capacity and is connected with the grease space in the ball-bearing steering-knuckle, so that one filling serves both parts, which have grease retainers designed to look after the effects of centrifugal force, gravity and capillary attraction. The steering tubes themselves form grease reservoirs; the joints are equipped with spring-loaded oil-retainers, and are also hung so that gravity tends to keep the oil from being lost. Oil is metered on the weepage principle before described. The steering box has a large oil capacity and an efficient oil seal at the point where the shaft emerges, which remarks also apply to the emergency-brake hand-lever mounting. The gearshift, foot-brake and accelerator-pedal bearings are all mounted on the power unit from which they receive their oil supply.

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The pedal bosses are held permanently in contact with flanges on the shaft bushings by the end pressure of a spring, which prevents oil leakage at this point.

The brake connections are of stranded cable working on segmental sheaves on the brake levers, a construction that does away with the possibility of rattle and the necessity for oil. The fan is mounted on the overhead camshaft, and the electric generator and self-starter are inclosed under covers on the engine casing. The universal joint at the top of the propeller-shaft is inclosed in the torque-rod head and is lubricated by pressure. The torque-rod head is of hemispherical sandwich construction, which renders it oil tight; it forms the rear cover of the gear box, from which source it receives its lubricant. The speedometer driving-gears are inclosed in a case that receives the splash from the universal joint. Throughout the chassis all oil passages are of large size in order to avoid liability of clogging.

NO GREASE-CUPS OR OIL-CAN HOLES

Automatic lubrication has not, owing to the complication involved, been applied to every part on this chassis, yet the large reservoirs provided in the few cases where manual oiling is still used have a sufficient capacity for several months' running. There is no grease-cup or oil-can hole on the whole car, while the average chassis has anywhere from thirty to sixty of these requiring repeated attention. As in other cars, the engine and rear axle must be kept supplied with oil, and should be occasionally flushed out with kerosene. The engine oil-filter must be kept clean, and the few oil reservoirs replenished every few months. This constitutes the total attention required in the way of lubrication.

The author is aware that the subject here discussed is not one of primarily scientific importance; it is, however, arousing interest at the moment, and with a view to stimulating discussion he would express himself as looking forward to developments in the "oilless" bearing method of construction as a solution to the problems involved.

DISCUSSION

CHAIRMAN D. McCALL WHITE:—The thimble bearing of the clutch-shaft at the end of the crankshaft has been satisfactorily lubricated by the use of a small needle-valve in the end of the crankshaft, this being provided with wicking to prevent overflow and operated by the clutch-pedal movement. This is used by the Rolls-Royce Company and by the Crossley Company in England. It has been proved to be absolutely satisfactory in that direction. Every time the clutch pedal is pushed out, a little squirt of oil comes through and lubricates that particular bearing from the force-feed lubrication system of the engine.

The universal-joint problem, which is a bugbear to us all, has been in a measure solved by the use of leather disks or disks made of

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similar bonded material. These cannot be used behind the transmission, when transmission brakes are used, as trouble always occurs. The General Omnibus Company of London and the Daimler Company of England have been using this construction for some years with great satisfaction. At first the leather did not give good results, but afterward they used a kind of bonded material called Hardy Thermoid lining. When transmission brakes are used it is an absolute impossibility to make those joints stand up, and in high speed work the centrifugal force itself is inclined to throw the joints out of line and probably will cause vibration.

Personally I favor inclosing all moving parts practically from the engine to the rear axle. Some years ago I patented a pump for the rear axle that fed and pumped lubricating oil through the universal-joints to the rear end of the transmission. That seemed to work out all right, then I thought it was rather complicated, so we endeavored to use a Hotchkiss drive, with a sliding universal shaft, or rather a propeller-shaft between the transmission and rear axle. We had a kind of castellation in there, a sliding castellation, at the end of which was a small pump plunger. We filled the plunger cylinder full of oil, so that every time the axle rose and fell, and shortened the distance between the transmission and the rear axle, the propeller-shaft pumped oil directly into the universal-joints.

The Rolls-Royce Company used to employ red-fiber bushings for the spring eyes, with satisfactory results. After seeing the Ford rear-axle dismantled, and viewing the red-fiber thrust washers therein, I must confess to a high appreciation of what red fiber really can resist.

It is difficult to know what to do with spring shackles. I would like to see the springs completely inclosed, but they cannot be very well bound up. A proper engineering thing would be to inclose the whole spring in an aluminum case, or something like that, but the casing seems to be out of the question because it will be so large. The lubrication system employed in the Fergus car appears to be complicated, but I believe that a more simple method can be devised.

F. H. FLOYD:—It is desirable to substitute oils for greases. Oils, when they can be applied, are better lubricants than greases. Oils however are fluid, except in cold temperatures; consequently they are inclined to throw off from the bearings and leave them dry. Largely because of the fluidity of oils, greases have been substituted.

J. EDWARD SCHIPPER:—The owner has often been accused of being neglectful, but the neglect is not always wilful. Many grease cups are neglected simply because the owner does not know they are there. He may take his new car to the service station for the first few months and after that the grease cups are forgotten, and it is not the owner's fault.

LUBRICATION OF JOINTS

The question of bush joints is a hard one to solve. It is another one of the compromises. I know of one case of a car equipped with

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hardened steel pins, with hardened steel bushings, and they still are used, but it is necessary to be very, very careful with the lubrication. Once the lubrication is right, good results seem to be obtained, with the hardened steel pin and hardened steel bushing, but this particular car drives through a yoke at the forward end of the torque tube. On some of the early product, where the lubrication was not correct, the rear axle moved toward the engine an appreciable amount after a short time, and the car became a "rattling good car."

There seems to be a necessity for a certain amount of oscillation before oilless or impregnated bearings work out well. Some of these bearings work out excellently, if there is 15 deg. or more oscillation, but below that point the distribution of lubricant does not seem to be as good as it might be.

A suggestion that has been made at times is the use of a graphite system. I heard the other day of an ingenious scheme for distributing graphite by means of a pendulum arrangement. The rougher the road the more the pendulums would swing and the more graphite would be fed to some of the bearings on the car.

The idea of a central oil tank has also been brought up in connection with chassis lubrication, but that would have to be arranged so that the oil stops feeding when the car is laid up in a garage. If the oil in the main tank is not kept in any great quantity, but is supplied intermittently by an engine pump, so that no great amount of oil at any one time is kept in that tank it possibly might work.

The wooden bearing has certainly shown its ability to stand up. There is no more severe stress on bearings than is given them by shock absorbers, say of the Hartford type; the impregnated wood there has certainly given good service. I believe that the bearing on the Truffault-Hartford absorber was changed from wood to metal about two years ago and was afterward changed back to wood again because the metal did not stand up under the severe stresses as well as the impregnated wood.

The only big objection to the use of oil instead of grease is the difficulty in getting an oil that works just as well in Texas, for example, as it does in Alaska. The oil makers have not been able to find such an oil, and it is doubtful if they will. A number of trucks, as well as passenger cars, are being fitted with oil cups in place of the grease cups used a year or so ago.

CHAIRMAN WHITE:—In marine engineering we used a bearing in the tunnel shafts made of lignum-vitæ; the propeller shaft ran directly in that with a bronze bushing shrunk directly on the main steel shaft. The bearing itself was made of lignum-vitæ or wood, and was lubricated simply by the sea water that passed the packing of the gland. I never heard of one of those seizing and they were built into all of the British battleships, and on most of the high-class high-speed mercantile vessels.

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DIFFICULTIES WITH GREASE

CORNELIUS C. MYERS:—Most of us appreciate that grease as a lubricant is a dirt carrier, as well as a lubricating substance. There is a great tendency on the part of a man who owns a car and attends to it himself to leave the cover off the pail of grease, and to scrape the dirty grease off his fingers or the grease paddle on the edge of the pail after he has filled his grease cups. That is one reason why we have trouble in lubricating parts and bearings with grease. It carries dirt, which lodges in various portions of the bearings or bushings, and it forces whatever lubricant is supplied to that bearing or bushing along a channel where it is possibly not effective. The oil-fed bearing has not that objection. The oil will spread, even if a little dirt is present. Many a time the grease cup on a car or truck is screwed down until it squirts out somewhere, and then the fellow screwing up the cup feels his duty is done. He quits with the feeling that that bearing is properly lubricated for some time to come, but it is not. Take down some axles and it will be found that sometimes the steering-knuckles are almost frozen with plenty of grease apparently applied to the bearings of upper pins. Another point is that unsuitable greases are used—and there are many grades of such greases.

A short time ago I was engaged upon the layout of a truck in which we decided to dispense with grease at every possible point, especially where it had to be fed often; that is, at the ordinary daily or weekly periods. The main trouble of course was with spring shackle lubrication. Plain oil cups would have to be filled once a day anyhow, possibly twice, to be sure that there would be no trouble. Now people will not, and ought not to be asked, to look after their grease cups or oil cups once or twice a day. As far as possible it ought to be a monthly proceeding, and it can be. I had previously tried out the wick oiler. It is very good, but is liable to damage by collision to such an extent that it is not reliable, so that we cast oil pockets in the spring shackles and brackets. The method of feeding the oil is quite important. If it is just allowed to feed to the pin by gravity all of it will very soon be lost, because the amount of vibration and motion between the surface is considerable, so that the oil feeds through very fast. We therefore allowed the oil to descend to the pin by means of a wick. An arrangement of that sort has a tendency to feed freely, so it is necessary to experiment with the material used for the wick, such as cotton or wool felt, or a mixture of cotton and felt. The design has this additional advantage—a teaspoonful of dirt can be added every time it is filled with oil, and the dirt cannot get to the bearings because all the oil is fed by capillary attraction to an aperture above the oil level. No matter how much dirt there is in the pocket it never gets down to the pin. No oil, or practically none, is fed when there is no motion in the pin. The minute there is any motion the feeding starts, and as a rule the more motion there is, or the more violent the motion is, the more freely will the oil be fed.

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USE OF WEEPAGE PRINCIPLE

The weepage principle has been mentioned by the author of the paper and has been utilized here too, by allowing the weepage to be carried by little ducts down to the spring leaves and allowing it to flow along the spring leaves. In pleasure car service it might be objectionable if the oil fed freely, but on a truck, at least, there is no objection.

The same design principle can be applied in many ways. Another one is to make the rear spring shackle hollow and put the oil in the shackle. It sounds as though it would make a rather large and clumsy shackle, but really it does not. Considerable capacity is available in the shackle for oil, and it can be fed in the same way.

This method is a little expensive, but it is all a question of whether the result will warrant the expense. The details described may seem crude and cumbersome and in time some one will probably devise a better and cheaper method of doing it. Then everybody will use it, for there is no question in my mind that we will use oil in almost every case rather than grease; we will also use some method of oil-supply that feeds according to the need. It must be a method that will not transfer the dirt to a bearing. In the method described the bearing is constantly clearing itself of dirt. It will accumulate on the outside of the shackles, but not on the inside of the bearing. Some trucks have been running for three years with the wick-oil method of feeding, and there is hardly a thousandth of an inch wear in the pins and bushings. They are still a beautiful fit, and very little wear has occurred at the sides.

K. W. ZIMMERSCHIED:—Oilless bearings are yielding enough so that the load is distributed over the whole surface of the pin. We know what troubles we have with bronze bushings. It is necessary to run them in to get a complete seat, thus wearing off the high spots on the bushing; but from the start an impregnated asbestos or other bushing of that sort gives a complete bearing over the whole surface of the pin and therefore wear will be very slight.

A MEMBER:—A cock-plug on a gas lamp is operated at temperatures from 300 to 400 deg. fahr. The best lubricant for such a plug is oil similar to the one used in the lubrication of a cylinder, mixed with finely divided graphite. The graphite is distributed to the working surfaces, and even though the oil disappears the graphite lubricates the bearing. I should think that graphite circulated with oil by some such system as has been mentioned would result in an efficient lubricant. Even though the oil became viscous and did not circulate in colder climates the presence of the graphite at that time would help out.

COMPARISON OF GREASE AND OIL METHODS

M. TOMLINSON:—I have recently been developing a car of the popular-priced type, and the question of chassis lubrication came up. In a popular-price car we could not go into an elaborate system, so

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for our own benefit we built two cars, one with cups of the oiler type and one with grease cups of the pin type. The cars were exactly the same. We used what we called a packed pin, fed from the end same as a grease cup. The felt wick was packed tightly. The opening was on top or away from the loaded side. The felt surface, clearance and a small oil plug were practically the same size as with the grease cup on the other type. We found in weather from 10 deg. below zero and up that with the grease we would get squeaks in from one to three days. With the oiling type we got nothing for seven days. The oil cups were filled once in eight days, while the grease cups on the other car were filled three times in the same length of time, proving to us that the oil was satisfactory. Using a small spring-clip cap for the oilers, the operator could pass along the car, and with his oil can simply lift up the cap and shoot in the oil.

G. W. KEEN:—Would it be possible to incorporate a pressure release in the main feed-line used in the Fergus car, and utilize the heat of the exhaust to thin out the lubricant, after which the pressure release would go out of action and feed the lubricant along the pipe line? Would such a system tend to liquefy the partly solidified lubricant in the pipes? The lubricant, while in a vaseline or heavy condition in the pipe, might be thinned in a comparatively short distance by the oil heated after passing through the gears.

A MEMBER:—The tendency should be to simplify the lubrication system more than to make it complex. I know of one car that has no less than 69 grease cups. Every 1500 miles service is given on this car. It takes three men an hour to lubricate it completely. Grease is used for lubrication. According to the instructions grease is depended on as much to force the dirt out as to lubricate the parts. It has been my experience that grease is a gatherer of dirt and will not wash off; whereas the ordinary touring car receives a washing at least once in a while. After water is put on a car at heavy pressure, the grease will still adhere, whereas the oil will be readily removed, leaving the surface practically clean and in that way washing the grease off.

O. E. HUNT:—It seems to me that any engineer will almost surely agree with Mr. Schipper when he says that the average owner has extreme difficulty in finding the grease cups. I believe that if every engineer in the industry discharged his garage man and greased his own car, a tremendous improvement in chassis lubrication would result.

EXTENDING CENTRAL LUBRICATION

I want to call attention to some instances where little difficulties have been encountered in extending central lubrication to points that are ordinarily not so lubricated. We made an attempt on one of our former chassis to lubricate a clutch front bearing with oil from the rear-bearing. It was a ball bearing housed in the rear end of the crankshaft. Means were provided to pass oil from the engine rear-

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bearing through the clutch bearing, and then to return it to the crankcase. The system was fairly successful, but it had to be discarded finally, because the clutch bearings rusted out, the difficulty being that the ball bearing could not be kept flooded with oil and the breathing action of the crankcase carried moist air through the bearing constantly and produced rust. At present in our twelve-cylinder engine we protect a ball bearing at the lower end of the timer from rust by providing a trap in the oil return from the timer base, which seals the return and prevents breathing action through the timer ball bearing.

In the conventional type of chassis, with which the transmission is on the engine, the most clean-cut way to lubricate the front universal-joint is from the transmission. That is, make the transmission a central system from which the universal joint is lubricated, also the torque-arm front-end. The rear universal-joint could well be lubricated from the rear axle. The big gear could be used as a pump and a scraper arranged in the upper part of the case to scrape the oil from the big gear and feed it into the rear universal-joint, which would be provided with a proper overflow to the bevel-gear case to keep the level from getting too high. In all such instances it is as necessary to keep dirt and water out as it is to keep the oil in. It is important then to boot such jobs. I would like to ask Mr. Chilton what means he proposed to use to keep dirt and water out of oilless bearings for spring bushings. I believe that the wick-fed oil-lubricated spring bushing with large capacity reservoir, such as Mr. Myers has described, is the most attractive spring-bolt lubrication means that has yet come to my notice.

RUBBER BUSHINGS ADVOCATED

G. A. Breeze:—Some parts of the chassis need not be oiled if proper provision is made for something to take the place of the oil. Rubber, properly confined so that it cannot be chafed, will take the place of lubricant. If we did not have grease, or if it cost a little more than it does, we would try to get away from it.

Some parts of my car connected with the radius-rods rattled and I found that by putting rubber blocks on there and confining them properly the parts would stand up all right, and would not wear out.

I believe a rubber bushing can be inclosed in a housing so that the rubber cannot spread far enough to deteriorate, and can be used at that point in place of oil or grease. I know that you can from what I have already done. Rubber can be used in steering-knuckles; that is, in the ball joint on the end of the arm.

I think that rubber confined in a housing could be used to take the place of several parts that have previously been lubricated or rather not lubricated.

Chairman White:—In 1900 I was chief engineer for a large air compressor factory and we used to have a three-cylinder direct-coupled air compressor driven by an electric motor. It is probable

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that about 300 hp. at 300 rev. per min. was required to drive these air compressors. We coupled these compressors to the motor. We allowed about ⅛ in. clearance between the flanges of the two halves of the coupling. In that space we put a rubber bushing. Part of the head of the bolt pressed the rubber in so that the flange itself could be a certain amount out of line and yet it would always take the torque and the connection would be absolutely solid. It was necessary to use a molded rubber of pretty hard composition.

CORNELIUS C. MYERS:—A large rubber bushing was used on the front brackets of the Renault car. Its designers started with a small one, which pinched off. Then they tried a larger one. A number of Renault cars in New York and in the East have large front shackle brackets; there is a big rubber bushing in them, or at least there was when the car left the shop. But rubber deteriorates when exposed to the elements, and I know that a large number of those bushings were replaced with others of a different material. Rubber is attractive where there is a tendency to distortion, but it will not, as a rule, stand the load required in automobile practice.

F. H. FLOYD:—It might be interesting to give my experience in driving a car for 12,000 miles. My experience has been that mud and dirt are excluded when grease cups are filled uniformly. I wished to see how thoroughly I could lubricate a car and prevent wear. It is true that I had a chauffeur to whom I gave orders. However, I did not rely upon his efficiency, occasionally getting under the car myself to see that the work was properly done. I noted the length of time that it took to fill up the grease cups and started him in. Weekly I asked for a report, and took pains to check it up. I found that he had missed a few. More than that, I found that he was turning up grease cups weekly that were empty. It was much easier to turn grease cups up than it was to fill them. A 5-lb. pail lasted for the 12,000 miles.

My experience has been that when grease cups are filled uniformly, mud and dirt are kept out. After filling grease cups, the surplus grease was wiped off with a cloth, thus also preventing the accumulation of mud on the outside of the bearings. I found at the end of the 12,000 miles my car operated noiselessly, and the length of time that it took to lubricate it was not excessive.

If there are sixty grease cups on the car there are sixty places to run oil into. It will, I think, be difficult to get a circulation that is uniform to all of the bearings from a central reservoir, for the reason that the oil will follow the line of least resistance and pass out through some of the bearings, leaving the others dry.

In extremely cold weather the bearings that are in warm places will get all of the oil, and distant cold places will get none, largely because the oil has become a grease in consistency. It is largely for this reason that greases, through a multiplicity of grease cups, still have the advantage.

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AUTHOR'S CLOSURE

ROLAND CHILTON:—Mr. Floyd has had better luck with grease cups than most of us. Perhaps he had a little more patience when it comes to the job of screwing them up than the average man has. If everyone would follow the instruction manuals and squirt the grease cups full every few days we should be all right; but there are many men who will not do it. We must either persuade these men to do it or remove the necessity. I feel that it is absolutely hopeless to persuade the majority of users.

Mr. Floyd brings out the point that the reason grease is still used is that it is grease at the beginning and it is grease at the end; grease in winter and grease in summer. On the other hand oil can be very thin at one time and very thick at another, and with some lubrication systems that might give serious trouble.

Of course, the oil that we now use to lubricate our engines is subject to just the same climatic variations as oil that we use for the chassis; in spite of those troubles we still manage to get along with oil for engine bearings. If we have very cold conditions we must put in a pump that is husky enough, and we must use pipes that are big enough so that the oil in its coldest condition can be handled. On a cold morning the pressure will go way up, but it is not impossible to design a pump and a pipe system that will look after the oil when it gets thick and sticky. If we can make an engine system, which depends upon a pump, work satisfactorily in cold climates I do not see why the system should not be extended to the chassis.

Universal-joints make trouble when it comes to lubrication, simply because the centrifugal force has a "dryer" effect and keeps the oil flung well away from the bearing surface. In the Fergus car we remedied that trouble by having the universal-joints inclosed in the torque-rod, as is often done, but we fed the joint bearings by pressure from the pump. That car had plain bearings in the gear-box, which by the way gave a quiet gear box. The gear shafts and universal-joint pins were drilled, so that the universal-joints got full pump-pressure, and that settled the trouble there. Of course, this is easily applicable in cases where the torque-tube runs down to the rear axle.

STOPPING OIL FEED

Whatever oil system is used, it is essential to have one in which the oil feed stops when the car stops. In the Fergus car that result is obtained by taking oil in every case to the pressure side of the bearings, the side of the bearings that carries the load. I made this test of a Fergus car: I ran the engine slowly for a few hours with the chassis still and no oil whatever passed the spring pins. In the accompanying sketch (A) is the fulcrum pin; that is, the central pin, of the cantilever spring. The bronze-bearing bracket (B) is the one to which the spring was clamped. The fulcrum pin was adjustable and held by a large bolt, of which there were four on the chassis. A

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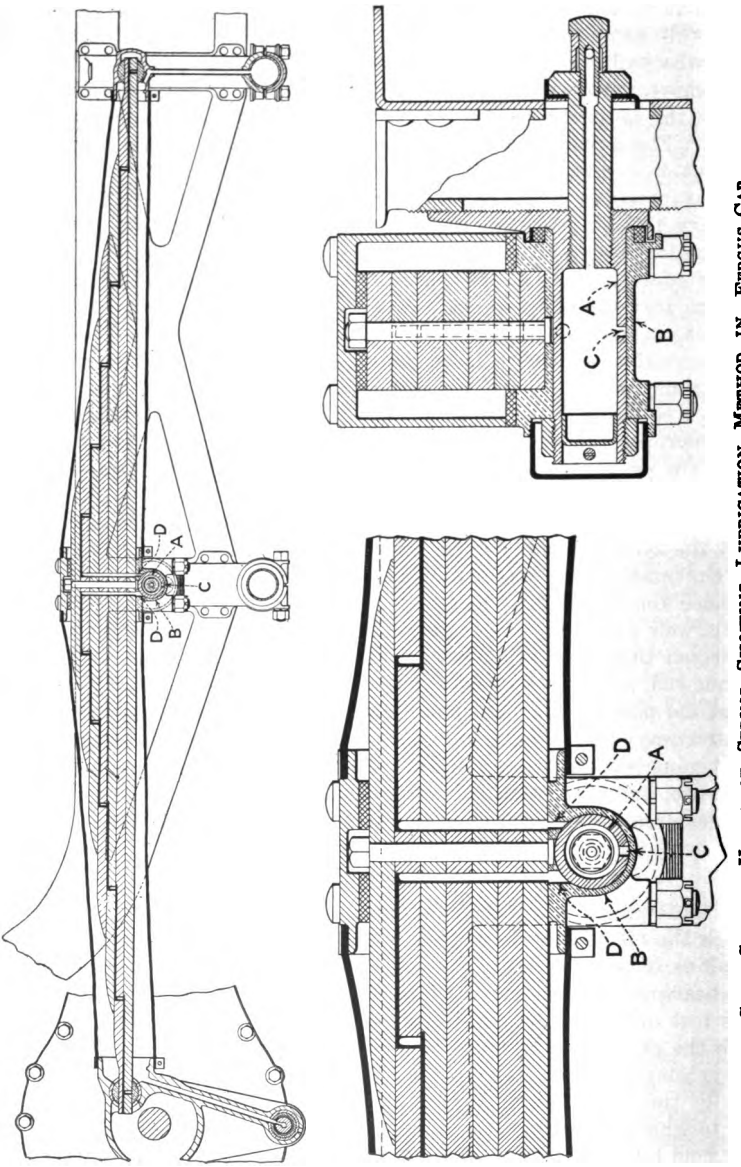
pipe line passes around the chassis, starting from the engine pump, and leading back into the sump. When the oil is not sticky the pressure is in the pipe line and is probably one or two pounds to the square inch. It would go up to a hundred pounds to the square inch



Cross-Section Views of Spring Showing Lubrication Method in Fergus Car

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if the oil was frozen. The pipe line passes close to the fulcrum pins with a branch hole leading into each. The oil holes (*C*) through the wall of the pin are on the side of the bearing on which the car weight always lies. Under these conditions the engine can be operated all the afternoon. The oil is circulating through the pipe, but no oil passes the point (*C*). The weight of the car keeps the end of the oil-hole sealed. With the engine running if the car is bounced by two or three people jumping up and down in it, it will be five or six minutes before the oil will pass through the holes and feed the springs. The outlet holes through the bushing (*D*) pass through the leaves, so that the oil must work all the way around the clearance in the bushing before it can get along the grooves in the spring. To show how efficient this method is in getting weepage through a bearing: we had the trouble at first of getting far too much oil through the system. The reason was that the bolts that fixed the springs to the bracket are at each end of the bearings, thus bringing the big load on the bronze casting at each end. As our casting was not stiff enough, it slightly "bellied." The heavy bearing pressures were at the end and the light ones in the middle. We had to alter the bearing—to stiffen it up with a rib. It was necessary to so fit that bushing that there was a high zone in the middle; with a clearance in the middle it fed too much oil. If fitted, the bushing was fitted so that the high spot was present in the middle. A day's run on the road would be necessary before the oil reached the very end of the system and traveled along the springs to the shackle, or rather the substitute for shackle that we used in this car. Of course, this point is met by oiling the parts when the car is put together.

The wick feed is a good scheme, and was used in the old gas engine days to lubricate crankshaft bearings, but as I remember it every time the engineer stopped the engine he had to pull those wicks out to avoid flooding over night.

In thinking of automatic lubrication the first thing seemingly that comes to mind is "complication." People seem to have a conviction that the car has sixty points to oil automatically, which is true. As against that the sixty grease cups constitute in themselves a degree of complication. There is very, very little on the outside of the Fergus chassis to show that it is automatically lubricated at all. A pipe line passes inside of the frame members and around the chassis, the spring shackles are not of orthodox construction (but are less complicated construction than the orthodox) and apart from the pipe line there is nothing to indicate that the chassis is oiled at all.

OIL RADIATORS REQUIRED

I hardly think that it is necessary to heat the oil because the engine itself is a good oil heater. The trouble is that the oil gets too hot. It may even yet be necessary to put oil radiators in for that reason. All that is necessary is to have the pumps husky enough and the pipe system strong enough so that it will not burst under

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unfavorable conditions, during the few minutes after starting before the oil has been dashed about and before the heat of the engine has thinned it out. Parts may break, but after all it is a simple matter to make them so that they do not break. It is just a matter of adequate strength.

Mr. Hunt also raised the point of rust in the ball bearings, and that reminds me of a similar trouble I experienced in this Fergus car. I inclosed the magneto and put a vent into the magneto cover because I fancied that otherwise any reduction of the pressure under the cover might cause an oil leak from my oil retainer. One day the car stopped. We took off the cover of the magneto, which was covered with what I might describe as a cobweb of rust. The whole of the wiring was covered with a sort of mist, and I take it it was due to this breathing action that Mr. Hunt mentioned.

The oilless bearing is the less susceptible to effects of dirt. I think that with a very soft bushing and a hard pin, dirt will do less harm in oilless bearings than in the others, although, of course, dirt should not be present in either of them. Grease itself does to a certain extent act to keep the dirt out, but when the dirt has got in, a dry bearing would be better. When we have a very hard hole to lap out, and it is too hard to turn, what we do is to get some good hard dirt, or emery, we call it, and some oil, and go to work. We do not get results until we put in some oil, but grit and oil make a very fine lapping compound.

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HEAD-LAMP GLARE—WHAT IS IT?

By J. B. Replogle

(Member of the Society)

It is my intention to confine this paper entirely to the question of what constitutes glare and of how it can be measured. This, of course, precludes any discussion as to the relative merits of different methods of eliminating glare, which in itself constitutes subject matter for a paper.

I know there is such a thing as glare, because I have encountered it many times. I know that it has been legislated against, so in order to find out what it is I wrote the police authorities in many of our principal cities, inquiring how they formulated the prohibitions against glare and hoping thus to obtain some definite information on the subject.

ANTI-GLARE ORDINANCES

Letters were sent to the authorities in fifty-eight cities. We received a very generous response, including ordinances from twenty-three cities. Of the total number communicated with, 55 per cent have no ordinances. Some of the remainder cover the matter by rules as follows:

Boise, Idaho—Blinding lights or searchlights prohibited.

Buffalo, N. Y.—Dazzling or blinding light, or a lamp or light exceeding 20 cp. with or without reflector, prohibited.

Cheyenne, Wyo.—Should not give forth a blinding glare, but should shed a rather subdued light.

Chicago, Ill.—Unlawful to use acetylene, electric or other bright head-lamp, or any head-lamp, the rays of which shall be intensified by any parabolic or condensing reflector, unless such head-lamp shall be properly shaded so as not to blind, dazzle or confuse other users of the highway or make it difficult or unsafe for them to ride, drive or walk thereon. Inspection board provided.

Cincinnati, Ohio—Similar to Chicago, but shading or dimming upper half of lens is deemed compliance.

Cleveland, Ohio—Lighting device is prohibited that concentrates and projects any part of the light into a beam, unless the said lighting device is so adjusted that at a point, a distance of 75 ft. or more in front of the vehicle, no part of the reflected beams of light shall be visible more than 3 ft. above the surface of the roadway.

Denver, Col.—Same as Chicago.

Grand Rapids, Mich.—Same as Chicago with the addition that the use of amber glass (so-called) as a screen, shall be deemed a compliance when effective.

Louisville, Ky.—Dazzling or glaring head-lamps prohibited.

Milwaukee, Wis.—Lamps prohibited that project main light rays above a plane that shall strike the roadway more than 200 ft. forward from base of vehicle on a horizontal roadway.

Omaha, Neb.—Head-lamps must be so focused and directed that the uppermost rays shall not be elevated more than 6 ft. above the surface of a level roadway at a point 100 ft. ahead of the lamp. Must be dimmed by being suitably shaded or covered so that there shall not be a glaring or dazzling effect.

Portland, Ore.—Head-lamp shall be so controlled that it will not blind, dazzle, or confuse other users of the streets or make it difficult or unsafe for them to ride, drive or walk thereon.

San Francisco, Cal.—Must be so dimmed or covered that the glaring effect of head-lamps shall be done away with.

Salt Lake City, Utah—Light prohibited of such power or strength as to dazzle pedestrians or drivers of vehicles moving in opposite direction.

Toledo, Ohio—Same as Chicago.

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The city of Baltimore, Md., has gone into the matter more thoroughly than any other city from which I heard. I shall therefore give the Baltimore ordinance almost in its entirety as being representative of the most painstaking attempt to cover the situation.

BALTIMORE LIGHTING ORDINANCE

Definitions

The term "headlight" shall be taken to embrace any lighting device designed to display a light on a motor vehicle in the direction in which said motor vehicle is designed to proceed, the term including what are commonly denominated as "side lights" when the same are fitted with reflectors and equipped with electric bulbs or other means of illumination of more than 4 cp.

Maximum Standards

No motor vehicle in use in Baltimore City (including motorcycles) shall be equipped with any electric bulb or other lighting device of a greater rated capacity than 30 cp., no matter how the same may be shaded, covered or obscured.

No "side light" shall be equipped with any electric bulb or other lighting device of a greater rated capacity than 4 cp. unless shaded, covered or obscured as hereinafter provided.

Operation and Control

No motor vehicle, including motorcycle, shall be operated within the limits of Baltimore City equipped with any device by which the headlights can be switched or cut off or on, covered, shaded, deflected, dimmed or lowered from the seat, unless the headlight itself is equipped with some means of preventing glare, which has been approved by this Board. In short, the ordinary "dimmer" or auxiliary light operated by a switch from the seat will not be permitted unless the headlight so operated is itself so shaded or constructed that even when cut in from the seat, it will not produce glare.

Oil Lamps

Unless an oil lamp of exceptional brilliancy be used, no device to prevent dazzle or glare will be required. Where, however, oil lamps of great brilliancy are used, some anti-glare device as hereinafter prescribed shall be used with the same.

Gas Lamps

All gas headlights (or sidelights of over 4 cp.) shall be equipped with some anti-glare device as hereinafter prescribed, this provision to apply to motorcycles as well as all other motor vehicles.

Electric Lamps

All electric headlights (or sidelights of over 4 cp.) shall be equipped with some anti-glare device as hereinafter prescribed, this provision to apply to motorcycles as well as all other motor vehicles.

Anti-Glare Devices

The use of any headlight of not over 30 cp. shall be lawful when the glass in front of the same shall have been covered or coated with tissue paper, paint, frosting or any other substance or material of sufficient opacity to prevent the outlines of the flame or electric light being visible when looking through the glass from the front. If desired, a circular space of not over 2 in. diameter may be left clear in the center of the front glass or a space of not over 25 per cent of the entire area below the level of the bottom of the flame or bulb. If these latter options come to be abused by motorists to such an extent as to defeat the purpose of the ordinance under which these rules are adopted, this portion of this rule permitting any portion of the front glass to be clear will be revoked by the Board without notice.

Acting under the authority conferred by Section 5 of Ordinance No. 630, approved May 27, 1915, the Board of Motor Vehicle Headlight Inspection has heretofore approved, and will from time to time hereafter approve certain special devices designed for the prevention of glare. Motorists are authorized to use any such device, and upon purchasing the same are given a certificate from the dealer to the effect that the same has been duly approved by this Board. The ordinance provides in effect that said certificate, when displayed to any police officer will render the motorists immune from arrest under said ordinance. Such plan and the use of special devices so approved furnish the motorists a final solution once and for all of the headlight problem, and their general use will at the same time go far towards obviating the necessity for more drastic legislation upon this subject.

No certificate issued by the Board as to any special anti-glare or non-blinding device is effective, according to its terms, unless such device is properly adjusted as directed by the maker. Motorists should therefore be careful in the first instance to see that such devices are properly adjusted,

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and, in the case of those apt to get out of adjustment, thereafter to see that they remain in proper adjustment. Most of the devices approved by the Board are not susceptible of improper adjustment, and such type of device is naturally to be preferred.

In view of the dangers attending driving at night without adequate light, the Board does not approve the extinguishment of headlights out-right. The devices above described all yield sufficient light to make night driving safe, but at the same time overcome the dangers attendant upon the use of glaring headlights.

EFFECT OF LIGHT ON HUMAN EYE

After an extensive study of ordinances dealing with glaring lamps, I found that the only reference made to a unit of measurement was one in which the candlepower of the bulb was specified. Inasmuch as the effect produced by a lamp of a definite candlepower varies greatly in accordance with the method by which the light rays are reflected, the candlepower unit is a meaningless one when used in this connection. One significant fact stands out prominently with reference to the majority of the ordinances; namely, that wherever the effects of a glaring head-lamp upon users of the roadway are described, the expression used is: Make it difficult or unsafe for them to ride, drive or walk thereon. An endeavor to determine why glare renders use of the highway difficult or unsafe directed my attention to a field of investigation upon which the conclusions in this paper are based.

It is a matter of common experience that the glaring effect of a head-lamp is to a great extent a function of its surroundings. For example, in broad daylight the brightest head-lamp does not cause inconvenience, while a head-lamp that is ordinarily considered as being well dimmed, may, if directed upon a dark road, produce extreme discomfort and constitute a real menace. This fact led to an investigation as to effect of light upon the human eye under various conditions.

It has been found that if a light be suddenly flashed into the eye of a person who has been for some time in a dark room, the pupil quickly contracts until the area exposed is but a small proportion of that to which it is dilated while in the dark. The same phenomenon occurs when a person in subdued light is looking at an object that is so poorly illuminated as to be barely visible. The pupil is dilated so that the retina of the eye can receive as much light as possible from the object viewed. If then a bright light is suddenly thrown into the eye, the pupil contracts, so that while the same amount of light as before is coming from the object viewed, but a small portion of it can reach the retina of the eye and produce vision. This reduction of vision the ophthalmologist calls "depression in visual function."

Glare is noticeable when light is reflected from the surface of glazed paper into the eye of a person reading by concentrated artificial light. Characters plainly visible when the paper is held at such an angle that it does not appear as a polished surface become illegible when the reverse is true. This is due to depression in visual function resulting from the greater proportion of light from the source that strikes the eye.

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DEFINITION OF GLARE

A qualitative definition of glare can now be proposed: Glare is depression in visual function due to contrast between the direct illumination of the eye from a source of light and the illumination of an object it is desired to view. *This glare is prohibitive when the object of vision is difficult to discern.* Accepting this hypothesis, we next approach the question as to a unit of glare and how to measure it. Assistance in consideration of this subject can be had by considering certain factors used in the measurement of light.

The illumination expressed in foot-candles produced by a source of light on any surface is equal to the luminous intensity of the source expressed in candlepower divided by the square of the distance, in feet, of that surface from the source. Thus a surface placed 1 ft. away from a 15-cp. source will have an illumination of 15 foot-candles. A surface 2 ft. away will have one-fourth as much illumination or 3¾ foot-candles.

The effect of a perfect parabolic reflector is to reflect all the rays from a point source at the focus in a direction exactly parallel to the axis of the reflector. An object within this beam of light is as brightly illuminated at a distance of 50 ft. as it is at 1 ft., hence the rule given does not apply when the rays are focused.

Many believe that intrinsic brilliancy alone is the cause of glare, and, so far as the discomfort caused by glare is concerned, this seems reasonable. But a comparison of a naked light with a light of the same intrinsic brilliancy in a parabolic reflector shows that the blinding effect is not due alone to intrinsic brilliancy.

Let us see if the unit of glare is related to the unit of illumination, the foot-candle. It is wise to establish a unit that can be applied in considering means for remedying a recognized evil.

Let us consider the matter as related to the pedestrian, equestrian or driver of team or automobile. A psychological peril is always present when animate intelligence is confronted by a powerful swift-moving machine. There is the probability of man or beast becoming frightened at the approach of such a machine and of his precipitating himself into danger. The presence of bright lamps on the front of the machine certainly tends to increase the natural apprehension and thereby the danger. If we make it safe for those possessing animate intelligence, *provided they retain self-control,* I think that is all that can be reasonably expected of the engineer. We can make it safe for them only if they can see their way with sufficient clearness to avoid the ditch on one side and the approaching machine on the other. As the driver of the team or machine requires more room than the pedestrian, and, as the consequences of running off the road into the ditch are so much more serious, we will confine our attentions to the approaching driver.

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RELATIVE LIGHT INTENSITY

In the city or town, the roadway is as a rule fairly well illuminated by street and store lights so that the approaching driver can suffer considerable depression of visual function without losing sight of the road. But in the country, on a narrow high-banked road, with a deep ditch on each side, and no illumination but that provided by the head-lamps, the peril becomes most acute. We shall therefore consider only this extreme condition. We shall here refer to the driver of the machine or team who is confronted by the head-lamp under consideration and not primarily to the driver of the machine carrying the head-lamp. The approaching driver is most of all concerned about seeing the road so he can steer his team or machine safely. To be able to do this, *there must be a minimum ratio between the intensity of light shining in his eyes from the approaching head-lamps and the illumination of the roadway.*

This is proved by common experience among automobilists that, when a dazzling head-lamp is approaching so that the driver facing it is blinded, if he in turn throws on his own head-lamps, they will, if they are more luminous than the opposing ones, so reduce the glare in his eyes as to enable him to drive safely. This is not due to the head-lamps of one car overcoming or neutralizing those on the other, as some suppose. What really happens is that the stronger head-lamp illuminates the roadway in front of and beside the approaching machine more than the approaching head-lamp illuminates the pupil area of the eyes facing it. Although just as much light enters the eyes from the head-lamp as before, the contrast between the illumination of the eye caused by the head-lamp and that of the roadway has been very much decreased and the glaring effect correspondingly reduced. In applying this information to the problem before us note that the principal places whose illumination are of interest are (1) the roadway that the approaching driver must see in order to steer correctly and (2) the eyes of the approaching driver. A strip of road measured from a point not more than 4 ft. in front of the head-lamps and say 8 ft. wide measured from the left-hand edge of the machine to the ditch can be taken as the road area the approaching driver is striving intently to see. The eyes of the approaching driver will not be less than 3 ft. from the ground in the most extreme case; they will be perhaps 25 to 50 ft. from the head-lamp. Under these conditions the eyes facing the head-lamp will be dazzled by the glare if the light striking them is much more intense than the light from the head-lamp that strikes the area mentioned.

ELIMINATION OF GLARE

My suggestions therefore are (1) specify an area (*a*) on the roadway that the approaching driver must be able to see; (2) specify an area (*b*) within which the eyes of the approaching driver will come at a time when he must see the roadway to avoid danger, and

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(3) specify a relation between the illumination of area *b* and that of area *a* such that glare will not result.

The space covered by area *a* should not begin more than 4 ft. in front of and not less than 8 ft. to the left of the extremities of the machine carrying the head-lamps. Area *b* should not be less than 3 ft. above the level roadway, and 25 ft. in front of the head-lamp.

If the illumination at *b* is more than four and one-half times that at *a* the light is glaring. This factor (four and one-half) was determined as follows: A ring was placed at a point 25 ft. in front of the head-lamp and the brightest spot in the beam directed upon it. The illumination on this bright spot was measured. A group of objects were placed below the head-lamp as representing obstacles in the road. An observer was placed so that he looked through the ring at the road obstacles and adjusted the light upon the road obstacles by means of a rheostat until they were sufficiently visible to make it possible to drive safely by them. The illumination of the obstacles was then also measured. In our experiments the illumination at the ring was four and one-half times that of the obstacles under the conditions specified.

Several forms of illuminometers are already available by which the measurement of illumination can be made. Two of these are the Sharp-Millar illuminometer, designed by Prof. C. H. Sharp of the Electrical Testing Laboratories, New York, and the Macbeth illuminometer, which was the type of instrument used in my experiments. These instruments are both expensive but I have made a simple and inexpensive form of glare meter, the basis of which is an ordinary pocket flash-lamp. This instrument can be produced by an instrument manufacturer for a small part of the cost of these more elaborate instruments and will be sufficiently accurate to permit the police commissioners to make their determinations with a satisfactory uniformity.

In Fig. 1, *T* represents the ordinary tube containing the battery of a pocket flash-lamp, *L* is the bulb of the same, *S* is the switch found thereon and *R* is the rheostat wound upon the outside of the tube whereby the resistance between the battery and the lamp can be varied at will within large limits. Mounted upon the lamp at the end of the tube so as to slide freely back and forth thereon is a photometer proper, which consists of the inside screen *I*, outside screen *O* and the eyepiece *E*. On looking through the eyepiece *E* two surfaces are observed, the screen *I*, which is illuminated from the lamp of the photometer or glaremeter, and the outside screen *O*, which is illuminated by the source of illumination being measured. The photometric head slides backward and forward to such an extent that when slid back the inside screen *I* is illuminated four and one-half times as much as when the photometric head is pulled out. This condition is secured by having the dimension *H* in the drawing equal to 2.121 times the dimension *M*.

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The instrument is used as follows: Assume a certain position as representing a place on the road it is desired to illuminate, set the photometer or glare meter with the head pushed back as far as possible on the tube, adjust the light on the inside screen *I* by means of the rheostat *R* until screens *I* and *O* are seen to be equally illuminated with the light shining on *O* from the source in question, surface *O* occupying the position representative of the point in the road it is

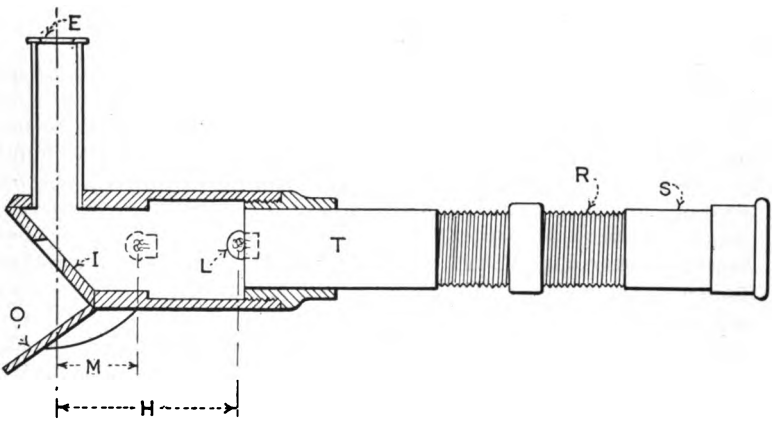

FIG. 1—INEXPENSIVE FORM OF ILLUMINOMETER FOR MEASURING GLARE

desired to illuminate for the convenience of the approaching driver. Now pull the photometer head as far as possible, walk back to the spot that is representative of the place the approaching driver's eye will occupy and inspect as to whether surface *O* is more brightly illuminated than surface *I*. If it is more brightly illuminated, the lamp is a glaring one, according to the definition given in the paper.

AUTHOR'S CONCLUSION

Legal restrictions attempt no definition of glare and therefore lead to confusion. They agree that the effect of glare is to render use of the roadway difficult or unsafe.

Glaring effect of a head-lamp is dependent upon environment. A bright light causes contraction of the pupil of the eye and thereby prevents clear vision of dimly illuminated objects. This effect is termed depression of visual function.

The effects of light are measured as candlepower, mean spherical candlepower, mean spherical candlepower per square inch and foot candles. Glare being a matter of relative illuminations must be considered from the standpoint of the unit of illumination, which is the foot-candle.

If we make it safe for other users of the highway to face our

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head-lamps, provided they retain their self-control, we have done enough. It is safe for them, though possibly still uncomfortable, if they can see clearly the road they wish to travel. They can see the road clearly if the illumination of their eyes by the head-lamp is not more than four and one-half times that of the road. This illumination can be measured by standard illuminometers, or by the special instrument developed by the author and described in this paper.

DISCUSSION

DR. LOUIS BELL:—Several years ago I conducted a series of experiments in which the question of the nature of glare came up. The depression of visual function is a complicated subject, depending only to a moderate extent on the relative opening of the pupil, because providentially we are so organized that contrasts seem about the same to us, providing these contrasts have the same numerical value, no matter whether the total illumination is rather bright or dim. Another matter must be seriously considered; that is the phenomenon characteristic of glare beyond that of the mere radiation of an absolute amount of light on the objects illuminated. When a light is of a highly "glaring" character, the beam of light entering the eye has several unpleasant effects. In the first place, the eye is not a perfect optical instrument. The beam of bright light entering the eye forms its clear image on the retina. It also is more or less scattered by the media of the eye, so that there is something of a halo about the image, if the light is very bright, because the scattered light, in the case of an intense beam, increases in intensity until it becomes unpleasantly visible on the retina. Then, too, the eye is not fully opaque outside of the pupil. Light can and does enter at the iris, particularly if it is not heavily pigmented. It also enters through the white, the sclera, of the eye. Indeed, it is a common experiment with ophthalmologists to send in light through the sclera and illuminate the whole fundus of the eye. The result is that when a bright light is facing a person, the image is formed on his retina; there is light surrounding it, owing to the scattering of the light in the media of the eye and to the light that comes in through the body of the eye. This stray light makes it so hard to see a comparatively faintly illuminated object. If the light forms simply a sharp and clean image on the retina without any straying at all it is comparatively easy to see even a fairly faintly illuminated object.

OPHTHALMOLOGICAL VIEW OF GLARE

The criterion from the ophthalmologist's standpoint is that glare begins when the stray light that does not form a clean retinal image is sufficient to be of about the same order of magnitude as the light received from a nearby object in the field of view. That is what is experienced when a person looks at a bright head-lamp in front of him. He sees not the image of the front of the lamp, but a halo of

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light all around it. When that is comparable in brightness with the light received from an object in the vicinity he fails to see that object because it is not on a dark background any more; it is on a rather light background.

Perhaps the simplest definition of glare in that sense would be to say that a lamp, a head-lamp or anything else, produces glare when its image is so expanded as to interfere with the visibility of things about it. We will notice that particularly with a powerful bulb in a perfectly clear head-lamp the beam streams down upon us. We see nearby objects, but cannot see things near the lamp itself. That is glare in the ophthalmological sense.

The criterion Mr. Replogle put forth seems to me to be really a question of differential illumination as between the light on the road, which is produced, perhaps, chiefly by a man's own head-lamp and the light that comes at him. If we can get enough light on the road, we can beat through those factors of glare and still can see quite well. A person is much more nearly immune with a powerful head-lamp of his own than he would be if he were traveling with a 15-cp. lamp and the other fellow had one of 70 cp. The moral of this condition is that it is desirable to keep the light low; keep it where it will not get into the driver's eyes. Fortunately that is not an extremely difficult thing to do. If our head-lamps were placed a little bit lower, it would be still easier. Some of them are up rather high to meet the requirements even at a short distance.

EFFECT OF INTRINSIC BRILLIANCY

The small difference made by intrinsic brilliancy, which Mr. Replogle has mentioned, is a well-established experimental fact. For example, we cannot tell at a distance of a few hundred feet whether a big arc lamp has a diffusing globe on it, providing that the illumination received as measured in foot-candles at the eye is the same. Intrinsic brilliancy only comes into play within small distances. At other distances it makes absolutely no difference for the same illumination, whether the intrinsic brilliancy is high or low. We can really forget the question of intrinsic brilliancy providing the illumination is the same. The illumination measured in foot-candles is the critical thing, because that, in the last resort, tells whether the light is sufficient to see by, or whether it is just going to fail.

In head-lamp construction and design, we have to look out for a little more than the effects at short range. Two cars approaching each other at 30 m.p.h. are moving together at the rate of 88 ft. per second. The drivers of these cars must make up their minds what to do a long time before they get inside the 25 or even the 50-ft. limit. I think, therefore, that more light is needed over a comparatively long distance. Most drivers would prefer 250 ft. to 25 ft. as the critical distance at which they should be able to see what to do, because it takes some little time to set the brakes on a car. A man's own reac-

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tion time, the time it takes him to see something imminent, to get his foot on the brake and get the car to a stop is several seconds. Every vehicle may be considered as carrying in front of it a danger space equal to the braking space, the shortest distance in which it can be stopped. So we must watch carefully and get visibility of the object far enough ahead to be outside the limit set by the two danger spaces of the two moving vehicles. This limit may be two hundred yards for interurban electric cars. In the case of an automobile, which can travel anywhere from 30 to 100 ft., according to its driver's promptness, we must consider the space covered during his reaction time and the braking space as well. So that, as a practical matter, we must consider all driving conditions, not merely those when cars are fairly close together—of course, it is important always to see where we are going to drive, but we must see things quickly enough to bring the car to a halt because of a dangerous condition on the side of the road.

RESULTS OF ADJUSTING LAMPS

E. F. WACKWITZ:—In some of our States where there are laws prohibiting glare we find that most accidents are due to insufficient light, rather than to glaring light. While the laws specify the value of the light that should be given, and also the path it should take, they also state that there should be no glare. The Massachusetts law, I think, is a reasonable one, in that it defines only the path the light should take and states that there shall be no glare above 3½ ft. In the ordinary head-lamp having the true parabolic reflector, everyone is thoroughly familiar with the result when the props are tipped down we get various results, but they are not altogether satisfactory. In one case, if the lamp filament is adjusted so as to get a pencil beam and the lamp is tilted down we get a streak of light from each lamp. If, on the other hand, we adjust to get a wider beam, it lacks length. Also, when adjusted for width of beam, we find it requires excessive tilting of the props, in which case it throws the strongest portion of the light near the car—when, as a matter of fact, the light should be some distance ahead. Had the bending or tilting of the props proved at all satisfactory, I do not believe a meeting of this kind would have been called. When the filament in a lamp is longer than the focal distance, we get from any point in the reflector a fan-shaped ray, and while adjusting the filament would correct the beam from one-half of the reflector, that from the other half would show increased glare in proportion.

Frosted lenses served temporarily to satisfy police officers, but the driving light was not satisfactory. It was improved, however, when 50 or 60-per cent frosting was used, and properly placed in relation to the filament, that is, if the filament is placed back of the focus the frosted part should be at the bottom, in order that that part of the ray that is inclined upward will be diffused, and the upper part of the reflector, which throws the down-

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wardly inclined rays, can be used for driving. In either case, whether the filament is placed forward or backward of the focal point, and the frosted portion placed correspondingly at the top or bottom, we have only one-half efficiency—one-half of the reflector throws a distant beam, the light from the other half being diffused. In fog, mist, or rain, this is very objectionable.

Assuming that there was nothing better than the true parabolic reflector for head-lamps, the first corrections were made with the lens. These varied in character—in some the upper beam was thrown downwardly so that it would be parallel to that from the lower part of the reflector. These, and other modifications, were decided improvements over the frosting. With all these different types, we had both good and bad features; we had some objectionable features, which required entering another field. We tried out various devices that could be attached to the bulb, or to the reflector, in order that the light reflected from the lamp might be thrown on the roads without passing through a distorted lens.

When a car is approaching, it is not difficult to determine whether the lamps are glaring. I believe that as long as reflected light is objectionable, or causes discomfort to pedestrians, or oncoming vehicles, it will be considered as glaring, and as long as there is no instrumental measurement made there will be disputes as to whether a lamp glares; that is, if a given amount of light is required for safe driving.

We believe that a device that corrects the beam, as in the case with some lenses, or with an adapter attached to the bulb, entails loss. There is loss in re-reflecting the ray from an adapting device, which throws a portion of the light to either the upper or lower part of the reflector so that its rays may be parallel with the correct working section of the reflector. To offset these losses, we concluded that correcting the ray at the reflector was the only solution. In testing out different devices we equipped the car with two pairs of head-lamps, spaced at equal distances, and tried them out in separate pairs under the same conditions, by operating a two-way switch. We used the same kind of bulbs, on the same batteries, on the same car, and with the same load in the car.

SATISFACTORY REFLECTORS

Of the different types of head-lamps and reflectors that received our attention, there were two which have proved satisfactory. These have been tried out in pairs, side by side, alongside of ordinary head-lamps tilted downwardly so as to arrive at their comparative driving values. One reflector consists of a distorted parabola, having two axes, the upper crossing the lower at an angle necessary to reflect all rays downwardly over a predetermined road area. The other is a parabolic reflector with a single axis and a parabolic curve that grows progressively larger from the top of the reflector, for 180 deg. on either side. Inasmuch as the focal point for any parabolic section

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of this reflector is at a different point within certain limits along the focal axis, we have a focal space rather than a focal point, as with the parabolic reflector. With the filament properly placed within this space, and slightly above the local axis, all rays are inclined downwardly. The light projected on the road is desirable for driving, and in length and breadth satisfies all legal requirements.

Both of these reflectors, when accurately made, with a filament accurately made and placed, will show no glare. They will effectively illuminate the road for 150 or 200 ft. Reflectors can be so constructed that there will be no glare, and assuming that lamps are most efficient when the correction of the beam is made at the reflector, and that the relation of the filament in the bulb to the reflector can be cared for in the adjustment, there seems no reason why such a device will not meet every requirement.

Satisfactory results can be obtained only when every adjustment is right. The inclination of the beam should be such that it will not rise above the horizontal when the rear end of the car is loaded down. Where this is neglected, varying the load in the car is likely to pitch the light so that even at a distance of 100 ft. there may be direct rays as high as 6 ft. Better results, however, are obtained when adjustments are made to light a certain road area, say about 150 or 175 ft. ahead of the car. The driving light in this case will be more satisfactory, and there will be absence of glare above the horizontal, even when the rear of the car is loaded down.

A great deal is claimed for the different reflectors, lenses and adapters now on the market. Even with 40 or 50-cp. bulbs, as used with some of these devices, it is impossible to see any great distance through fog. We find that diffusing devices illuminate the mist or fog directly in front of the driver, and thus render driving most difficult.

J. T. CALDWELL:—The subject of glare merits the consideration of all those in any way interested in improving night-driving conditions of automobiles. It is of particular interest to the Society of Automotive Engineers, the Illuminating Engineering Society, and the American Institute of Electrical Engineers, as well as to the manufacturers of incandescent bulbs, reflectors and other equipment used in automobile lighting.

Speaking from the standpoint of one interested in the manufacture of part of the lighting equipment—the bulbs—I am looking to the S. A. E. to decide upon the results that will best solve the problem. Once knowing the kind of lighting agreed upon as being best, the problem of producing those results must be solved by the manufacturers of the equipment.

GOOD HEAD-LAMP LIGHTING

There are at present many varied opinions on this question as to what constitutes good head-lamp lighting. It may be of interest to present the views recently expressed in a lecture, Light Projection—

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Its Application, given as part of a course under the auspices of the Illuminating Engineering Society and the University of Pennsylvania, at Philadelphia, in September, 1916, by Messrs. Evan J. Edwards and H. H. Magdsick, of the Engineering Department, National Lamp Works of General Electric Company. A part of this lecture follows:

The opaque projectors find by far their greatest application as head-lamps for vehicles. The first object in equipping automobiles with head-lamps was to light the way ahead for the driver. It is desirable that the driver of an automobile be able to see his way for several hundred feet in advance, and since he must provide his own light, and direct it unfavorably for lighting the roadway, it becomes necessary to project at high intensity. It was the effort to accomplish this, as well as to give ease of control, that brought about the rapid change from oil and acetylene units to the electric system employing closely-coiled low-voltage filaments in deep projectors, giving both accurate control and high efficiency. The intensities now vary throughout a wide range up to hundreds of thousands of candlepower, with an average of about 25,000 cp. But the higher intensity head-lamps have, in solving the problem of lighting the road, introduced a new and serious problem in that they temporarily blind the driver or pedestrian who happens to come within their angle of action. "Glare" is the one word most used in referring to the blinding effect of high candlepower head-lamps.

Factors Involved in Glare

It is generally agreed that the main factors involved in producing "glare' are included in the following:

1—The luminosity of the background.

2—Solid angle subtended by the source-projected-area at eye of observer; in other words, source size and distance.

3—Luminous intensity of source in direction in question.

At the present time automobile head-lamps are in almost all cases less than 1 ft. in diameter, and thus the size can be assumed as a constant in the consideration of "glare." Taken under the worst possible condition—that is, driving on a country road, in complete darkness—the luminosity of the background can be considered as zero. This is likely to hold true until all roads are artificially lighted at night. Thus, the luminosity of the background is also a constant at the present time as regards our problem when driving on the country road. This leaves but one controllable factor—the luminous intensity of the source in direction in question.

At present the limit of intensity that is considered fairly safe, and yet endurable, is an unknown quantity and probably varies with almost every individual. An unaccustomed driver naturally cannot endure as high intensity as a person who has driven a machine for a long time under various conditions. We must all agree that an intensity of 100,000 cp. is bad, and yet if we were to cut this intensity to one-tenth of this figure, there is still a great deal of "glare," assuming the worst conditions as stated above. Up to the present time, no method of measuring the relation between "glare" effect and candlepower has been adopted for a definite road condition; this is unfortunate and makes it impossible to measure the interference with vision. Under the worst conditions, as stated above, there is still an interference with vision, even with the lamps dimmed to almost the lowest degree. The candlepower must then be reduced to practically nothing before the "glare" completely disappears. On the other hand, a fairly high intensity can be encountered by a driver without any marked interference if the roadway is illuminated, as, for instance, in the extreme case of driving in the daytime with the head-lamps turned on.

Lighting Problems

If the problem were only to eliminate "glare" it could be easily accomplished by eliminating the head-lamp, but the problem presents itself from three standpoints:

1—The approaching driver.

2—The driver of the machine in question.

3—Safety to pedestrians and occupants of unlighted vehicles.

We must, therefore, limit the "glare" effect and yet at the same time have high intensity at such angles that it will illuminate pedestrians, the roadway and all approaching vehicles at a distance of from 100 to 200 ft. The proper regulation should include not only a maximum permissible intensity at upward angles, but likewise the minimum intensity for road illumination. It thus seems that the light from the angles above, say 4 ft. from the ground, should be practically eliminated and the light in the lower angles below 4 ft. from the ground should be retained. There can hardly be any other way to give sufficient road illumination and at the same time eliminate the "glare" from the point of view of the approaching driver.

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Several devices have been designed and many are on the market whose object is to reduce or eliminate "glare." Many of these reduce "glare" by decreasing the intensity of the beam, whereas others reduce or eliminate the upper light and redirect the intercepted light in downward directions. The simplest method of eliminating strong upward light is to tilt the head-lamps downward by an angle equal to one-half the angle of spread of beam. In most cases the head-lamps are not sufficiently accurate to give a well-defined beam. Another method is to set the light source back of the focal point of the reflector and cover the upper half of the door with an obscuring material. Another combination consists of an ellipsoidal upper half and parabolic lower half, which when perfectly made and adjusted gives no light above the horizontal. Still other devices consist of prismatic combinations designed to reduce the upper light by bending the reflected rays downward and to the side of the road.

Although each of the so-called "non-glare" devices now in general use may have its favorable point or points, none of them can be said to solve the problem completely. A lamp that gives no light above the horizontal has both its advantages and disadvantages when considered from the three standpoints mentioned.

Owing to the fact that manufacturers and inventors of certain devices already on the market believe their product to be the best, it is certain that all interested are not in agreement on the best solution of the problem at present. Therefore, it seems necessary to study the underlying principles and to conduct a series of tests as a foundation for future work.

Then, after the illumination results are agreed upon the next step would be the development of the equipment to produce those results provided that such equipment does not already exist. After that it would be well to interest the law-making bodies of the various States in adopting a uniform regulation.

SUGGESTED LAW

Messrs. Edwards and Magdsick suggest that such a law can be expressed entirely in units of length and candlepower and might be worded as follows:

"Head-lamps shall not have an intensity exceeding a certain amount, say, 20 cp., at any angle above, say 4 ft., above a level roadway, and shall have an average intensity of not less than, say, 10,000 cp., measured at equal vertical angular increments from the axis down to the road at a specified distance, say, 100 to 200 ft."

WILLIAM H. CONANT:—I have previously contended that glare is primarily a question of optics and should be approached entirely from the effect upon the nerves and muscles of the eye. Quantity of light is of little importance except as a relative term. As the paper points out, what is glare in one set of conditions is not in another. The author is well advised in selecting the worst possible conditions for measurement and definition of this difficult term. I think perhaps he overlooks the point that in defining the quantity of light to be specified at a point 4 ft. in front of and 5 ft. to the left of the head-lamps in question, he is leaving out of consideration the effect of other beams of the same light upon drivers who may be following the car, described in his statement as "the approaching driver," and others that may be following at a farther distance. It would seem then that, in addition to specifying quantity of light at a certain location adjacent to the car, it would be just as necessary to define the shape of reflector in order that other rays than those enlarged upon in the paper should also be controlled and directed.

AUTHOR'S CLOSURE

J. B. REPLOGLE:—The word "glare" is jargon, and was not intended to be used scientifically or ophthalmologically at all. I am not

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talking about glare from an ophthalmological standpoint at all, but from the point of view of an automobilist interested in it as a head-lamp proposition, pure and simple.

Dr. Bell has said that a 25-ft. distance is too short. I know it is, and suggest that the matter should be considered from a double standpoint—the "close" standpoint and the "far" standpoint; we could then determine whether the divergence of the rays was proper. If the divergence of the ray is sufficient at 25 ft., it certainly would be safe farther back. That is the reason I made 25 ft. as the closest point up.

We must not only consider the subject from the standpoint of the driver of the automobile meeting the driver of an automobile, but from that of the driver of the automobile meeting a horse. The horse is not extinct yet, and he is not likely to be for a few years; until he is extinct we must consider the question from his standpoint, and he does not carry a head-lamp. Consequently we must not depend upon the illumination of the road by the approaching machine that is going to be "glared." We must depend on the illumination of the road by the head-lamp under consideration.

Mr. Wackwitz considered mostly the methods of eliminating glare. There are just two ways of eliminating glare—decrease the light in the eyes of the approaching man or increase the light on the roadway. It can be accomplished in a variety of ways, but after all there are only those two ways of eliminating the danger. That is borne out by Mr. Wackwitz's statement that many accidents are reported due to insufficient light. That does not mean insufficient light in the eyes of the driver of the car, but insufficient light on the road.

I believe we require a unit of glare. There is a vast amount of confusion in the minds of those who are trying to eliminate glare because we have no precisely-formulated conclusion as to what glare is, and until we get that we are working in the dark.

Mr. Caldwell quoted the statement that the only controllable factor is the luminous factor. I believe that we have two—the luminous intensity in the eyes of the driver and the illumination on the ground.

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INDIANA SECTION PAPERS

A STANDARD OF CARBURETER PERFORMANCE

By Prof. O. C. Berry

(Non-Member)

Carbureter performance is often reported in terms of engine performance. This may serve the purpose when it is desired to compare the merits of different carbureters for use on a given engine, but it does not throw much light upon the performance of the carbureter itself. As a standard of carburetion, it is far from satisfactory. We ought to establish a standard of carbureter performance that would be expressed in terms of the ability of a carbureter to perform those functions for which it was designed.

Opinions may differ as to the proper division of the requirements placed upon the carbureter and those placed upon the intake manifold of the engine, as both influence the quality of the carburetion. For this reason no attempt will be made to enumerate all of the functions that a carbureter should perform. We will probably agree that usually: (1) It must be a good mixing device; (2) It must avoid decreasing the volumetric efficiency of the engine; (3) It must supply the engine with the best mixture of fuel and air for each speed and load at which the engine is capable of running.

(1) To be a good mixing device, the carbureter should cause the proportion of fuel and air to be the same in every part of the charge supplied to the engine. In order to do this to the best advantage as much of the fuel as possible must be converted into a gas, and the remainder must be so finely divided that it will float along in the air in the form of a fog. To gasify the fuel, heat must be added. This can be done by heating the charge of air, or by causing the fuel to impinge against a hot plate. Atomizing the fuel also helps in gasifying it. One of the best ways to accomplish this is to introduce it into a stream of rapidly moving air so that the directions of flow of the fuel and air will be nearly at right angles to each other. After the fuel has been properly atomized and gasified, it must be thoroughly and uniformly mixed with the charge of air.

(2) An ideally perfect carbureter will supply the mixture at the engine throttle at atmospheric pressure and unheated. Under practical working conditions it is obviously impossible to produce a carbureter for our present commercial gasoline that can meet this requirement perfectly, as condition (1) must also be met. There must be an appreciable vacuum in the body of the carbureter in order to produce the air velocities necessary to atomize the fuel, and

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the addition of heat to the mixture is required in order to gasify the fuel sufficiently to get satisfactory performance, especially in the winter season. Because of both the vacuum in the carbureter and the heated mixture, the volumetric efficiency of the engine will be decreased.

The best carbureter that can be produced from this point of view will therefore be the one maintaining a sufficient vacuum to atomize the fuel properly and at the same time adding just enough heat to gasify the mixture. The amount of vacuum required will depend

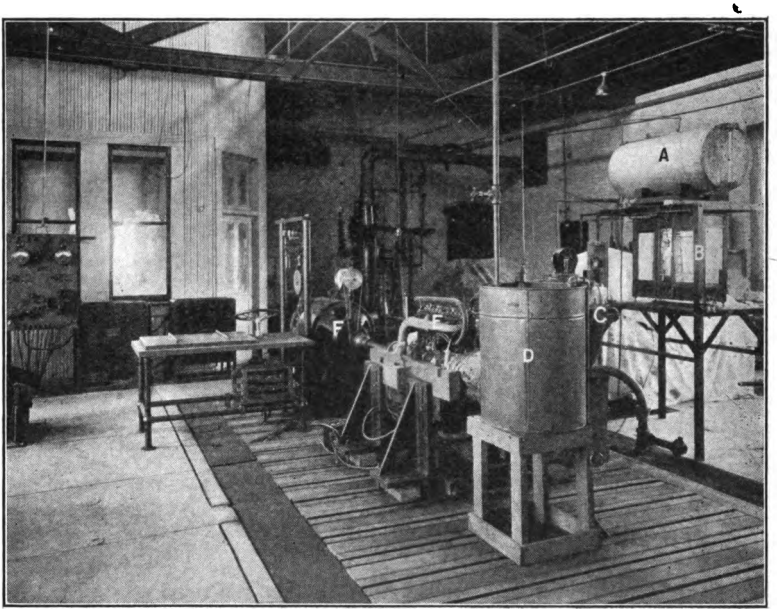

FIG. 1—VIEW OF TESTING LABORATORY AT PURDUE UNIVERSITY

partly upon the scheme used in atomizing and partly upon the character of the fuel. The amount of heat required will also depend partly upon the way in which it is applied and partly upon the character of the fuel. More and better experimental data are needed in order to determine how to atomize the fuel to the best advantage and how to apply the heat; also the pressure difference and the amount of heat necessary to produce the desired results with any given fuel.

PROPER FUEL AND AIR MIXTURES

(3) There is some difference of opinion as to just what the character of the mixture should be, and how it should vary with the speed and load of the engine. Is it true that a comparatively rich

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mixture is needed for proper performance when the engine is running slowly and unloaded, and that a lean mixture is needed for speeding? Or does the engine require the same mixture at all speeds and all loads? Is the mixture that will give the best efficiency the same as the one that will give the best power? If so, what is this mixture? If not, how much do the two mixtures differ, what are they in each case, and how much will the powers and efficiencies differ for these two mixtures? What is the maximum range of mixtures that can be used successfully in an engine to produce regular firing, and how will this range vary with the speed and load of the engine?

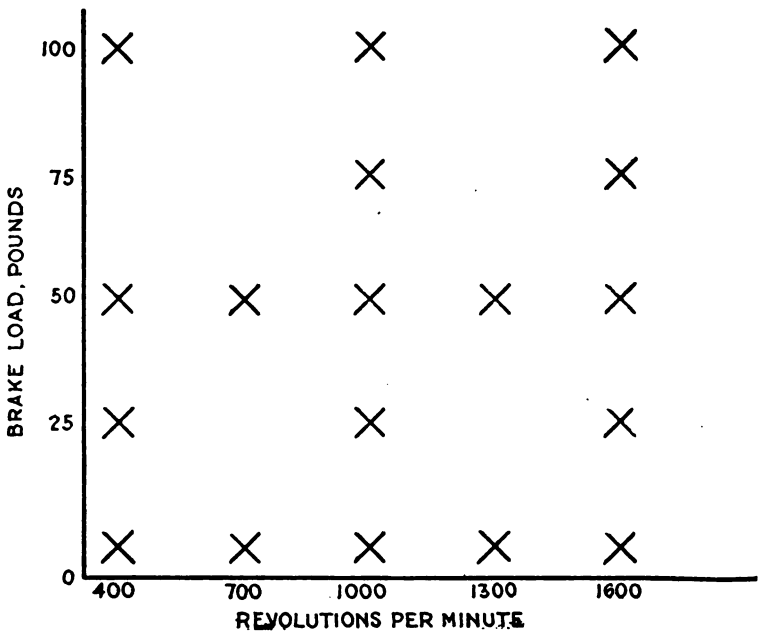

Fig. 2—Speeds and Loads at Which Tests Were Made

How will the power and efficiency vary as the character of the mixture changes?

Some experiments have been completed recently in the laboratories of Purdue University in an attempt to answer these questions. The tests were run on a Haynes "Light Six" engine connected to a Diehl electric dynamometer. The set-up is shown in Fig. 1. The gasoline was piped from the gasoline tank *A* into a 2-qt. vessel placed on one of the scale pans. In order to give the balances freedom of motion, the gasoline was siphoned from this vessel to the carbureter. The balances *B* were capable of weighing the gasoline to the one-

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hundredth part of an ounce, and were equipped with electrical contacts so that when they came to a balance they would start a stop-watch, a revolution-counter on the end of the engine shaft and would ring a gong on the air meter. This made it possible to take all of the readings at the same time.

DESCRIPTION OF TESTS

The air was measured through an Emco No. 4 gas meter *C*, reading in cubic feet, so that tenths of a cubic foot could be estimated. The meter was connected to the carbureter by rubber tubing, which was kept from collapsing by a coil of wire inside of it. The barometer was read, together with the temperature of the air to and from the meter, the pressure drop through the meter in inches of water, and the wet and dry bulb thermometers on a hygrometer. In this way the amount of air could be measured to within 1 per cent. The air leaving the meter was maintained at a temperature of about 90 deg. F., thus insuring sufficient heat in the mixture.

The supply of cooling water for the engine in tank *D* was kept between 125 and 135 deg. F. It was caused to circulate through the engine jackets by the pump regularly supplied with and driven by the engine.

The speed of the engine was read on a tachometer, as well as being computed from the stop-watch and revolution-counter readings, giving a good check on this important factor. The brake load on the engine was read by means of a sensitive set of Fairbanks scales, thus making it possible to compute the power developed by the engine to a satisfactory degree of accuracy.

Tests were run at the different speeds and loads indicated by the crosses on Fig. 2. The maximum brake load that the engine could maintain is about 100 lb., so that the loads were about zero, one-quarter, one-half, three-quarters and full. At the speed and load represented by each one of the crosses a set of tests was run in which the mixture of fuel and air was varied while the throttle opening was kept constant, and the brake load was so varied as to keep the speed constant. This was accomplished as follows: The carbureter was adjusted so as to give a mixture yielding good power and the dynamometer (*F*) and engine throttle were then adjusted to give the desired load and speed. For example, a load of 50 lb. and a speed of 1300 r.p.m. were selected to obtain the curves shown in Fig. 3. A test was then run at this speed, load and mixture, and the weight of gasoline per pound of dry air in the mixture, the power developed by the engine and efficiency computed. This gave the first point on the curves in Fig. 3.

The mixture was then made slightly richer by opening the gasoline needle, the throttle opening remaining the same, and the brake load being adjusted to bring the speed back to 1300 r.p.m. A second test was made under these conditions, and a point on each of these

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curves determined. This was repeated until the mixture finally became so rich that the engine would miss and could carry but a fraction of its original load. The mixture was then brought back to approximately the original point and a set of tests run with increasingly leaner mixtures until the engine could no longer perform properly. In this way the power and efficiency curves, Fig. 3, were completed. A similar set of tests was run at each of the speeds and loads indicated in Fig. 2, and curves similar to Fig. 3 were drawn in each case.

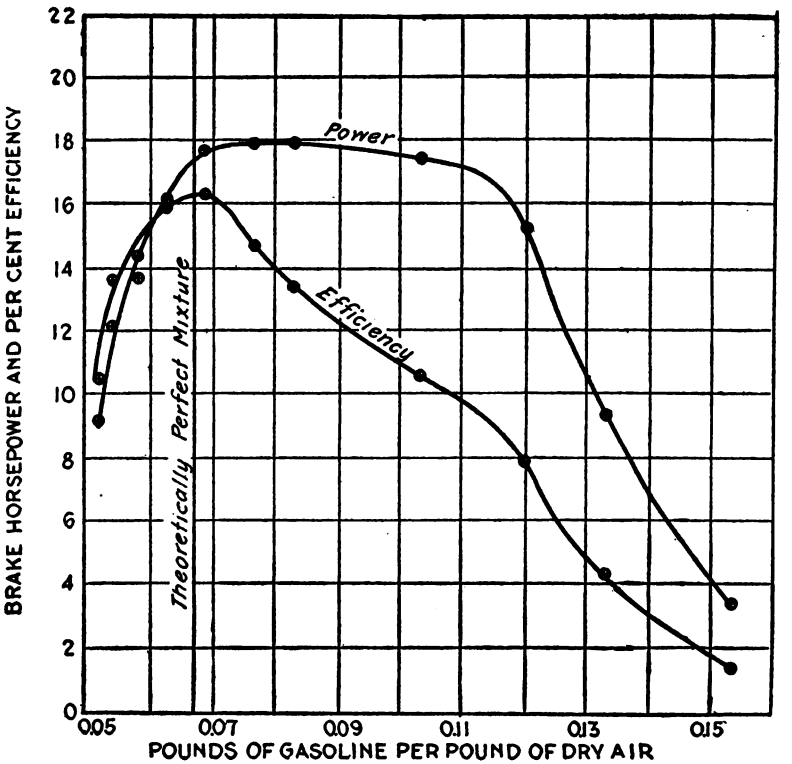

FIG. 3—ENGINE PERFORMANCE CURVES AT 1300 R.P.M.

The vertical line in Fig. 3 (at 0.0671 lb.) represents the theoretically perfect mixture of fuel and air, or the one in which there is just enough oxygen in the air to burn the fuel and no excess of either fuel or air exists. The curve shows that the engine will run with a mixture of less than 0.055 lb. of gasoline per pound of air, but will not pull well with so lean a mixture. As more fuel is added the power will increase rapidly until nearly full power is reached, when the curve becomes almost horizontal, increasing slowly to a

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maximum, then decreasing slowly for a time, but finally reaching a point where it falls off rapidly. The richest mixture with which we were able to run the engine was 0.155 lb., or nearly three times as rich as the leanest mixture. The engine will carry nearly full load with a mixture as lean as 0.065, or as rich as 0.115 lb. In other words, a carbureter can be adjusted with as lean a mixture as can be used to carry full load, and the amount of gasoline can be nearly doubled, without greatly affecting the power capacity of the engine.

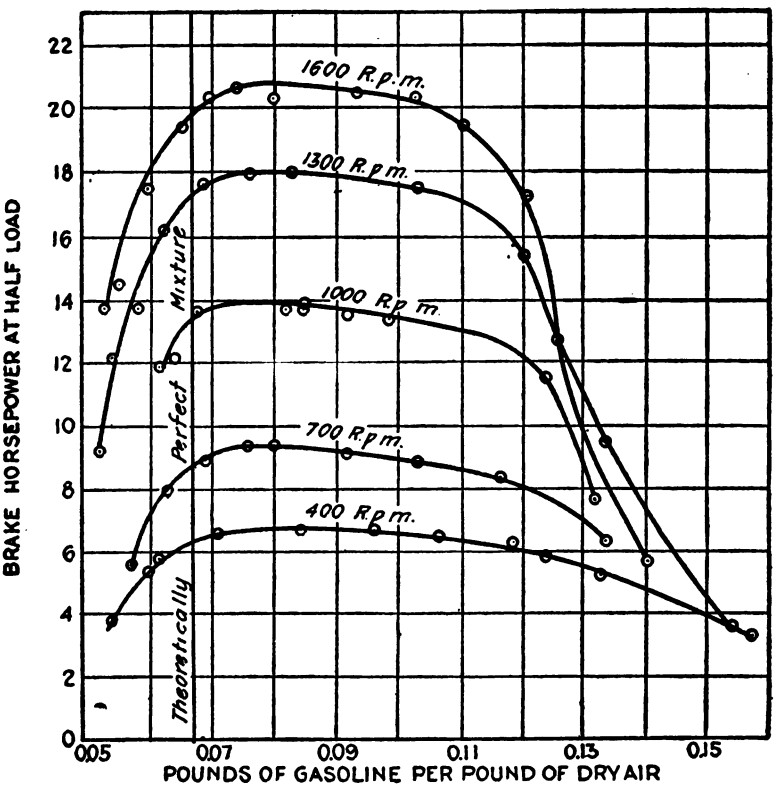

FIG. 4—PERFORMANCE CURVES AT HALF LOAD WITH DIFFERENT SPEEDS

POINTS OF HIGHEST EFFICIENCY AND POWER

It is practically impossible to stand by the side of an engine mounted on a test block and distinguish any difference whatsoever in its performance as the mixture is being changed through this range. A listener standing with his back to the engine could not

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tell at any point within these limits whether the mixture was being made richer or leaner. The effect of this change upon the efficiency of the engine is very different. The point of highest efficiency seems to fall almost exactly on the point of the theoretically perfect mixture. As the mixture is made richer than this the efficiency will decrease even while the power is increasing slightly, and will decrease rapidly after the point is reached when the power is also decreasing. Thus the point of highest efficiency comes with a mixture of 0.0671 lb., while the point of highest power is found near 0.08 lb. The efficiency of 16.2 per cent will be recognized as good indeed for a gasoline engine running at half load.

In Fig. 4 is shown a set of these curves taken at about half load, but at different speeds from 400 to 1600 r.p.m. They show that the mixture for maximum power is not noticeably affected by the speed, but that at high speeds the engine cannot hold up its power with quite so much excess fuel as at lower speeds. With leaner mixtures the power holds up about equally well at all speeds. The efficiency curves are not given in this figure but the tests show that the highest efficiency is developed with the theoretically perfect mixture in each case.

Fig. 5 shows a set of these curves for a speed of 1000 r.p.m., but for about one-quarter, one-half, three-quarters and full load. These curves show that at full load a slightly wider range of mixtures can be used than at light loads. The point of best power comes at about 0.08 lb. in each case, however, so that the curves simply show that with an open throttle, and a consequently higher compression, a mixture can be exploded which is a little further removed from normal than is the case with the closed throttle. The efficiency curves are not shown in this figure, but the point of highest efficiency comes at about 0.0671 lb. in each case.

EFFECT OF MANIFOLD CONSTRUCTION

The point may well be raised that the engine used had a wet manifold, and that the curves here shown are therefore not theoretically perfect. As a matter of fact the engine was chosen for its fine reputation for being able to fire regularly under adverse conditions in service. It upheld its reputation with us in a satisfactory manner. The intake manifold was entirely inside of the block casting, and was heated by the jacket water, as well as by the exhaust gases as they passed out to the exhaust manifold. We felt that the manifold construction was good, and that even a perfectly dry manifold could not have changed our results appreciably.

These curves offer an explanation of why it is that in two cars of the same make, both having good power, good acceleration and smooth running engines, one can travel 10 miles on a gallon of gasoline and the other 15 miles. One will have the carbureter adjusted so as to get a powerful, but lean and therefore efficient mixture, while the

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other carbureter will be adjusted to give too rich a mixture. This fact will suggest a rule to follow when adjusting a carbureter. Decrease the quantity of gasoline until the engine loses power and then increase it slowly until good power is restored, but not a notch beyond this point.

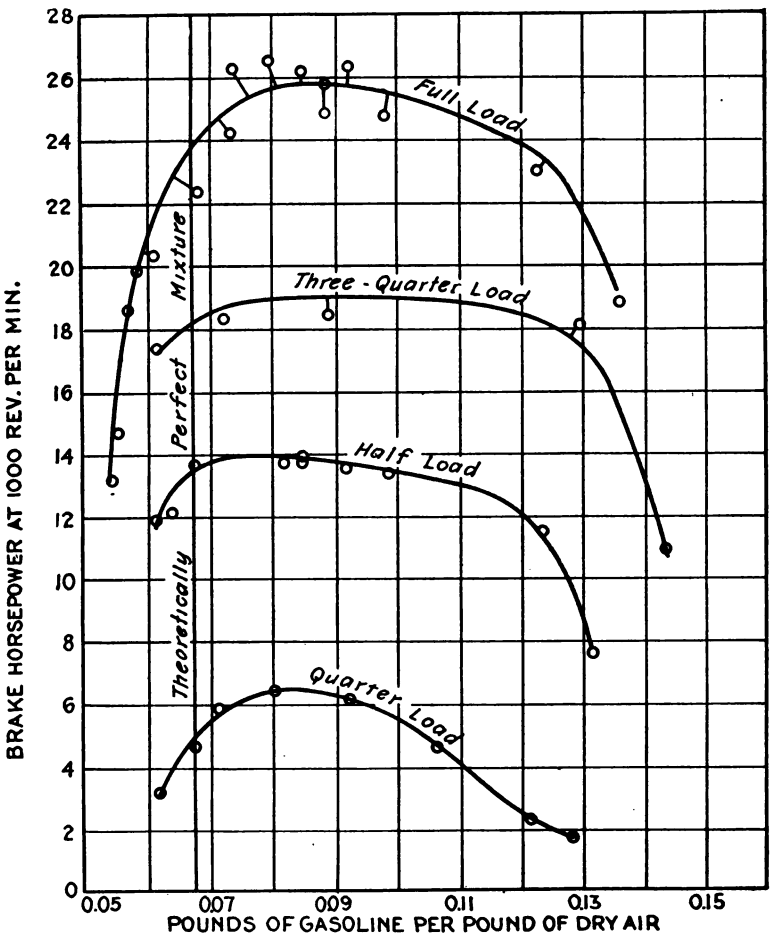

FIG. 5—BRAKE HORSEPOWER CURVES AT 1000 R.P.M. WITH DIFFERENT LOADS

There are numerous carbureters on the market which are not capable of much adjustment, but which will run on cold or on warm days equally well. They may enable the engine to start easily and still hit every cylinder after it is warmed up. They accomplish this in spite of the fact that a greater weight of cold than of warm air

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can pass through a given orifice, while the increased viscosity of the gasoline will cause less cold than warm gasoline to pass. Thus with the same carbureter adjustment the mixture is necessarily leaner when the fuel and air are cold than it is after they have become warmed up. This seemingly good practical performance of the simple or so-called fool-proof carbureters is due to the wide limits between which the mixture is capable of giving good power. The efficiency of these carbureters is low, for when they are adjusted so that the mixture is rich enough to start the engine readily, it will necessarily be too rich for the best efficiency after the engine becomes warm. This same line of reasoning shows the value of having a good means of adjusting the carbureter placed where it can be reached from the driving seat while the car is in motion.

AUTHOR'S CONCLUSIONS

A wide range of mixtures of gasoline vapor and air can be used in an engine to give regular firing in all of the cylinders. At half load and mid-speed on an automobile engine any mixture between 0.055 and 0.155 lb. of gasoline per pound of dry air can be fired, and practically full power will be developed between the limits of 0.065 and 0.115 lb. The highest power will be developed with a mixture of about 0.080, while the best efficiency will accompany the theoretically perfect mixture of 0.0671 lb. A change of engine speed apparently does not affect the mixture at which the best power or the best efficiency will be realized, or the ability of the engine to use the leaner mixture, but at the higher speeds a smaller amount of excess gasoline can be used successfully. A change in load does not noticeably affect the points of highest power with reference to mixture ratio or efficiency, but at the higher loads a wider range of extreme mixtures can be used. The engine can run idle with as wide a range of mixtures as it can use when pulling a good load.

The set of tests described is only one step in the large task of mastering the subject of the proper carburetion of petroleum fuels. Purdue University plans to continue its investigations, and it is hoped that other experimental laboratories of the country will join in publishing their accumulation of information upon this subject and enable us as a nation to get the most out of the use of our limited supply of fuel oils.

DISCUSSION

A. P. BRUSH:—Will Professor Berry state why the maximum power output is not coincident with the theoretically perfect mixture? Also, at what point in the enriching of the mixture does soot begin to appear on the spark-plug?

PROF. O. C. BERRY:—Two factors tend to enable the richer mixtures to give higher power than does the theoretically perfect mixture. In the first place the fuel is probably never quite uniformly mixed

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with the air, so that when the total air and gasoline are in proper proportion, some parts of the mixture are too lean. Then when a rich mixture is used the hydrogen tends to burn in preference to the carbon, leaving a deposit of carbon in the cylinder. The effect of this upon the power of the engine may be understood by analogy to the case where methane, CH_4, is burned. To burn 1 cu. ft. of methane requires 9.56 cu. ft. of dry standard air, and will produce 1072 B.t.u. To burn the hydrogen out of 2 cu. ft. of methane will require the same amount of air, but will produce 1392 B.t.u. Thus more power can be produced by the second method of burning.

My opinion is that the sooting is in almost exact proportion to the excess of fuel used, but that the effect in depositing carbon on the plugs will be much more noticeable when the mixture is rich enough to cause the engine to "miss" occasionally.

A. P. BRUSH:—All of us have seen engines that run in service and on the dynamometer without visible carbon deposit on the spark-plugs. I would like to determine the point in the mixture at which discoloration from carbon begins to occur. It would then show us the practical running range of mixtures.

We might define the practical running range of mixtures as from the theoretically perfect mixture to that point at which carbon begins to be deposited. It would be a valuable contribution if such a point could be determined before Professor Berry's apparatus is dismantled.

USE OF LOW-GRADE FUEL

J. W. ESTERLINE:—We have made an extensive investigation dealing with the use of low-grade fuels in automobiles, and that part of the investigation which was assigned to me was the burning of fuels in the form of a gas, rather than in the form of a vapor. We ran several cars on kerosene and fuel oil, however, and had the novel experience of going around the Speedway at 50 m.p.h. on some crank-case oil that a racing driver left in one of the cans in the pit.

We succeeded in obtaining a device that gave sufficient gas at a uniform pressure, at sufficiently low speed and at sufficiently high speed to operate the engine under practically all conditions of running. The device was simple, devoid of moving parts and could be regulated in an excellent manner. One car was run 3200 miles and the cylinders were clean at the expiration of the test and appeared to be well polished inside. There was no residue left either in the cylinders or in the gas generators.

We had no difficulty in getting the mixture to ignite. There was no smoke and no smell. The engine efficiency was higher when running on gas mixed with air than when running on a vapor from a modern carbureter. On one test we selected a sample of gasoline with a given number of thermal units per pound and a sample of kerosene with the same heat value. The gasoline and the kerosene were both used in the same engine, the gasoline being admitted through a modern carbureter and the kerosene through the gas generator. Tests showed

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that the efficiency on the kerosene was from 15 to 20 per cent higher than on the same engine running on gasoline and with the carbureter most advantageously adjusted.

In most of our work we utilized the exhaust heat from the engine for producing the gas. The only problem met was that of getting a production of gas at sufficiently low speed and an amount of gas proportional to the requirements of the engine at all times. This was successfully done, however, and the engine operated without difficulty.

The temperatures of the gas used were quite high, and our results showed that no doubt it would be necessary to design the engine to burn fuels at such temperatures.

We drove four different cars a total of seven or eight thousand miles, and reduced the operation of the apparatus to a point where it was quite reliable. An engine running on a gas produced in this manner is powerful, snappy and flexible and is at all times clean, provided the proper amount of air is mixed with the gas.

F. E. MOSKOVICS:—Was any attempt made to analyze the exhaust for various mixtures?

PROF. O. C. BERRY:—They were not analyzed, as these chemical analyses require considerable time, which was not available.

HEAT IS BEST REMEDY

V. R. HEFTLER:—Mr. Mock started his paper by recommending heat and small manifolds. The question of small manifolds is one that is very interesting. In our work we have found it advisable to have a ready means of determining gas velocities. We have found what we call the nomograph a convenient means of making calculations. This is based on the slide rule and the scales are slide-rule scales. They are extended or contracted according to what exponent of the quantity is used and are shifted one way or another according to what factor is to be used in multiplying that particular quantity.

I do not know what Mr. Mock's idea of a small manifold is—that is, how small can it be? That is a matter of compromise, but I would like to know where in his opinion it is wise to stop. I suppose the gas velocities depend on the sort of manifold. With a dry manifold the size can be greater. A wet manifold must be a very small one if we want to get good action. We have found in our experience that heat is a remedy for most carburetion ills.

If heat is applied to the manifold, the mixture range can be much closer to the ideal of smaller range, or we have high power and economy. If heat is not applied the mixture is wet. If we do not want to adjust the carbureter constantly, we must keep the mixture rich enough so that the lighter elements will be present in large enough quantity to keep the engine running under all conditions. Heat will therefore help economy. It will have its effect on the condition that exists when the throttle is opened. If a manifold is heated, the wet condition described will not obtain to such an extent; on opening

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the throttle, there will be more gas in the manifold. With a good manifold the throttle can be opened as quickly as desired and there will be no bark.

This explanation of what happens when the throttle is opened disposes of the wrong theory that for acceleration a rich mixture is needed. I believe Mr. Mock's explanation sets forth what we need. We may need more gasoline from the carbureter but we need the same mixture in the engine. That we need more gasoline at the carbureter to keep the same mixture at the cylinder is due to the time necessary to pass from a dry to a wet manifold. This will not happen if the manifold is properly heated. With such a manifold and with one not too large, acceleration can be obtained without any sacrifice of economy.

FREDERICK PURDY:—A manifold takes the mixture from the carbureter, which we assume has delivered at the throttle, or a little back of it, a proper mixture for the load at which the engine is running. It is my impression that what we really want all the time is a theoretically perfect mixture or as near it as we can get. It is quite absurd to assume that the mixture that gives the highest mean effective pressure is the mixture that we want all the time.

There are many curves inside the manifold. We cannot make them straight and feed all the cylinders. They cannot always have an even rise and an even length. If the manifold is not uniform throughout its length, the gas velocities must change rapidly, no matter whether the car speed is accelerated or retarded.

Mr. Esterline called attention to the fact that in a carbureter or in the device he used he got higher efficiency. I attribute that to the fact a gas was used. I saw some beautiful experiments made in Joseph Tracy's laboratory a couple of years ago on the burning of fuel oils; a portion of the oil was burned and the flame put out, but this portion raised the temperature of the remaining fuel to a point where a gas resulted, because the chemical composition of the material was changed.

NECESSITY OF ATOMIZATION

It has been said that a vapor was intended to be used in the original combustion engine. I believe the original one was developed to use a manufactured gas. A vapor is substantially a gas in which the particles are exceedingly small; the smaller they are the more nearly possible it will be to carry them when air is not present. For the same reason, fine dust will float, because of its own surface tension and the quantity of air it carries on its surface; the finer the gasoline is broken up, the more it will be subject to the movement of the air. The larger they are, the less subject they are to the movement of the air, so the more they will be affected by inertia. The best atomizing carbureter is desirable, largely for this reason, it seems to me. The finer the atomization, the more nearly gas will respond to the changes air is subject to, and that is the crux of this situation.

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I am not an advocate of extreme temperature, because I do not like to reduce the volumetric efficiency of the engine. In 1906, the bigger the engine, the better the car was considered to be, and the more we got for it, but conditions are different to-day. We use the smallest engine that will drive the car. The engine must be made just as efficient as possible. There is no advantage in reducing the volumetric efficiency in order to use gas at a high temperature. The economy will be higher when a higher temperature is used, because the gas will be vaporized and will be in almost a molecular condition.

We can only add a certain quantity of gasoline to the air and have it evaporate. That quantity at moderate temperatures is not sufficient to make a satisfactory running mixture so that a wet manifold is required. The object of a small manifold is to keep the speed so high that gasoline will be carried along the walls of the manifold at a uniform rate. The only reason for using a smaller manifold is because it is wet. It will not take up any more of the gasoline because it is running fast. If the air is passing fast enough over a body it will carry the gasoline along in small units, so that it will feed into the cylinder at a uniform rate.

The smaller manifold is not altogether the answer to the problem. I cannot say what the quantity of gasoline is that will be carried to the manifold in suspension. When the engine is cold, the air going into it is colder and heavier. The volume taken in is not greater, but the weight is, and it is pounds that count, not cubic feet. When the engine is cold, more fuel is needed. The air weighs more, so that the mixture is actually thin when it gets to the engine. In going over a mountain, the volume or cubic feet of air is the same, but the air is of lighter weight and the fuel supply must be decreased to balance it. The situation is reversed when the air and engine are cold. If the manifold is smooth enough, the mixture will be carried along the side more uniformly. Vents in the carbureter provide means for changing the speed of air slowly so that the inertia of the mixture will not stop it. If the mixture in the manifold is subject to changes in speed, and the elements are not thoroughly evaporated, the speeds must be changed so slowly that each element of the mixture can be kept up to the other. The heavy element will lag behind, otherwise. In some carbureters this is taken care of with a dashpot and some take care of it in other ways. If the direction of movement of the mixture is changed less rapidly, there will be a good deal less engine trouble. All the good engines that seldom miss are built with manifolds so that there is not such a rapid change in the speed or direction of movement of the gas.

MORE INTIMATE MIXTURE REQUIRED

A. P. BRUSH:—We have been told manifolds should be kept small, so they can handle liquid; that they should be heated, so there will not be any liquid. Is one or the other, or a little of both necessary? We have been told manifolds should not have corners, because that would

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make the fuel separate from the air; that the corners, which we should not have, should be heated, so that the fuel will be evaporated. Is it all of one, or a little of both?

I would remind you, in analyzing this subject, it must be remembered that liquid fuel is never burned; that a gas is never burned. The only thing that is ever burned in an internal combustion engine is a mixture of one gas with another; some hydrocarbon gas combined with two gases, nitrogen and oxygen. After all, we are building gas engines, and all the fuel is gasified before it begins to burn, and is mixed with sufficient intimacy with the oxygen to burn.

My belief is that we should do everything possible to secure segregation as promptly as possible after the fuel leaves the nozzle. It should be secured before the first bend of the manifold has been met or at that point. Two forces can be used to induce segregation—inertia due to a change in direction of the flow, and gravity. A drop of liquid is affected by gravity and will fall out of the air-stream if the velocity is sufficiently low. It seems to me, in place of trying to use small manifolds with few bends and putting the liquid into the engine and vaporizing it too late to secure a sufficiently intimate mixture with the air, so that it can all be burned, we should use this early segregation and throw the fuel into the air-stream in the shape of a fixed gas. Thereafter each bend and every change in flow produces a more intimate mixture between gasified hydrocarbon and the air.

The question of supplying heat in connection with carburetion should be studied from the standpoint of what we desire to accomplish, which is the vaporization of the liquid fuel with the least possible addition of heat to the entire mixture.

If all the manifold is heated enough to vaporize fully the fuel, the air is also heated to such an extent that the power output of the engine is reduced an undesirable amount. The same thing is true if the air is heated enough to vaporize fully the fuel within the time of its passage to the manifold.

The proportion of vaporized fuel to air should be only about 1 to 15; assuming that the entire amount of the fuel must be heated to 400 deg. F. to vaporize it completely, and that the air is not heated at all, then complete vaporization of the fuel will increase the temperature of the entire mixture only about one-sixteenth of 400, or about 25 to 30 deg.

The suggestion I make may and probably will prove to be the method of doing what we have been told we ought to do, but we have not been told how to do, namely, keep the density high enough to obtain good volumetric efficiency and not be in trouble winter or summer. If we can keep the air away from the vaporizing surface and make the fuel lie against that surface until vaporized, we are sure of a mixture which follows the flow of the manifold throughout its length and it is impossible to get too much heat into the mixture.

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CARBURETER SHOULD USE ALL FUELS

I would like to raise the question as to whether a kerosene carbureter would be a desirable instrument if it could be secured. If we should originate a carbureter that would run on kerosene and would not run on gasoline, I wonder if we would not reverse the present condition between kerosene and gasoline. Is not that carbureter and manifold arrangement which will handle a combination of all the non-viscous products of petroleum distillation the ideal device so far as petroleum-derived fuels are concerned?

FREDERICK PURDY:—Some time ago a carbureter was developed in which the primary mixture was carried in a small tube that was heated, alongside of which a great quantity of air was carried. This design did not prove to be very successful. I think Mr. Brush's idea is excellent and that it can be carried out successfully if we can find a way of doing it without having to use too massive a construction.

A. P. BRUSH:—My judgment is only that the manifold should be large enough. I believe that a horizontal portion of the header might be provided with a heated trough narrow and small enough to have small effect on the major air-stream, but so located as to take care of any condensation of the gasified fuel. I doubt that any perceptible condensation would occur in the largest manifold with the lowest-speed engine between the time of evaporization and delivery into the cylinders.

I believe the ponderousness of such a carbureter is not the problem of the carbureter man, but of the engine man. The former is through when he gives us an instrument that delivers a correctly proportioned mixture of hydrocarbon fuel and air. From there on, it devolves upon the designer of the engine. All of the energy and money and time that the carbureter companies have spent in devising means for giving a temporary excess feed of gasoline to compensate for defective manifolds has been due to our neglect or misunderstanding of the problem; the carbureter designer has been forced by the engine designers to make his instruments less perfect than they were before that line of development was started.

VARIATION OF SUCTION

C. P. GRIMES:—I would like to substantiate Mr. Mock's statement regarding the variation of suction. On a recent hill-climbing test, if the suction in the manifold fell below 2½ in. Hg., we could not climb the ascent, regardless of the make of carbureter or the size of the manifold. In our case it resolved itself into the question of whether we wished to close the throttle or build a manifold with a choke of the proper size, thus necessitating a compromise with speedway performance.

V. R. HEFTLER:—One of the most successful airplane engines used in France not only has the heated manifold, but also has hot air introduced in this way: all the exhaust passes around the intake. The

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intake is in the center of the exhaust muffler. At the high altitude at which these engines are designed to operate the temperature is so low that no heating arrangement can be too efficient.

A MEMBER:—I would like to ask Mr. Brush if the gasified fuel will be precipitated out at 150 deg. if it has been mixed properly with the air, or if the affinity will keep the two in suspension in a saturated form. The mixture is precipitated out, but only the excess leaves as the air temperature changes. Is the temperature of the air in the manifold low enough so that the proper amount of gas to give a proper mixture will precipitate?

A. P. BRUSH:—Taking both air and fuel at running temperatures, there is not time enough to vaporize the fuel from the delivery at the jet to the ignition at the spark-plug. The air in this room is probably so much below the saturation point with water at this temperature that it would take up a pitcherful of water. At the same time, I might throw a glass of water into the air, and the major portion of it would come down. Some of it would evaporate, but a very small part. I might spread the same amount of water over a sheet of cheese cloth, spreading it over a large surface, and that cloth would dry and the water would be in the air. There is no question that the time is too short for natural evaporation to diffuse the fuel. I am sure that even if the air is given heat enough, in time, to vaporize the fuel, it does not get to the fuel fast enough and that considerable-size drops of fuel pass into the engine as such.

A MEMBER:—I am not sure that a proper amount of gas will precipitate, but I thought it might from the fact that precipitation occurs from mixtures that have also been highly atomized. When a mixture leaves the jet, it certainly cannot form much of a stream; it is at least nebulous, but it does condense, even after that. The vapor is almost in a molecular state, so it is not likely that it will condense as rapidly as if merely nebulous.

F. C. MOCK:—The subject of carburetion is so broad and practical in every detail, that it is hard to tell where to start. Our present engines have not changed from the original design, which was intended to operate on gasoline vapor and air, but the fuel available has changed so we cannot always have gasoline vapor. I think that a great part of our trouble with engine operation is due to inefficiency in the gas charge. When we do not have proper fuel, the engine does not run right. When particles gather in liquid form, we cannot further control the flow, regardless of the care taken in design.

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OVERHEAD VALVE PROBLEM OF AN ALUMINUM ENGINE

By A. L. Nelson
(Member of the Society)

The day is not long past when a clearance between the tappet and the cam of 1/64 or even 1/32 in. was prevalent in valve mechanism. Year by year this clearance has been decreased in order to quiet the valve mechanism until now one of 0.003 in. is not considered excessively close for some types of engines.

The reason for this reduction of clearance is that the engine speeds have been greatly increased; the standard of quietness of valve operation has been raised even more in proportion than have the engine speeds.

The clearance between the end of the rocker-arm lever and the valve stem of the aluminum engine with valve-in-the-head construction and camshaft in the crankcase has an even more serious effect than its influence in producing noise, as will be pointed out later. The vertical expansion of the aluminum cylinder case is about twice as great as that of cast iron. Even for the cast iron construction the valve-in-the-head engine has gone on record as being a noisy type. Experience shows that with the ordinary type of valve mechanism the aluminum engine is even more noisy.

The object of this paper is to show how the disadvantages of the valve mechanism of the valve-in-the-head aluminum engine can be completely eliminated by a simple change of the conventional cam.

DIFFICULTIES WITH CONVENTIONAL CAM

The conventional type of cam when adjusted with a valve-stem clearance to give satisfactorily low valve closing and lifting velocities at the working temperature of the engine would hold all the valves open when the engine was cold. This can be explained by reference to Fig. 1, in which cam *1* operates lifter *2*, and by lifter-rod *3* rocker-arm lever *4* lifts valve *5*. The rocker-arm lever shaft *6* is fastened to the cylinder head *7* by a bracket *8*. When the cylinder case *9* is brought to its working temperature its vertical expansion is greater than that of the lifter-rod, since the former is aluminum and the latter steel, and also because the cylinder is subjected to a wider temperature range. Because of the unequal expansion of these two members, the rocker-arm lever shaft is raised more in proportion than is the top of the lifter-rod. Assume that the engine has the desired valve-stem clearance when hot. Then when the engine is stopped and cools, the reverse of the above expansion takes place; the valve-stem clearance is decreased, not merely on account of the differing ratios of expansion of the metals, but it is multiplied by the ratio of distance B to A, which in our case is 2.348.

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It has been found by experiment that the valve-stem clearance has to be at least 0.013 in., so that the valves will retain sufficient clearance to start a cold engine. With this clearance and the conventional cam, the valves opened and closed with such high velocities that the

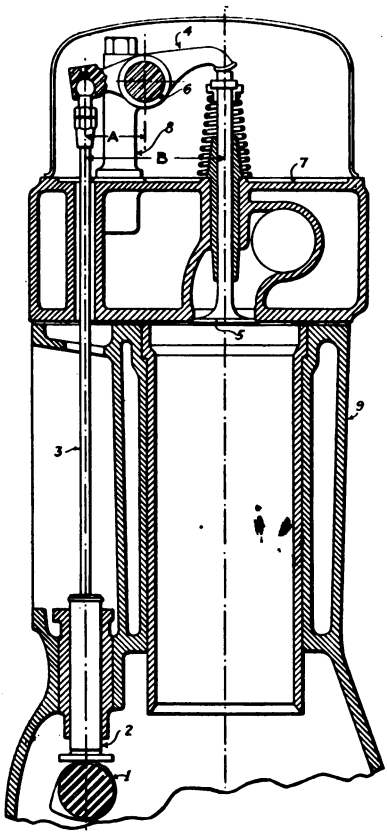

FIG. 1—OVERHEAD-TYPE VALVE MECHANISM

valve action was entirely too noisy. The impact on the valve seats and on all the valve-mechanism parts made the wear very appreciable. The clearance would not hold up without frequent adjustment. It therefore became necessary to make a radical change in the method of operating the valves. The simplest method which analytically, as well as practically, proved to be the most satisfactory was worked out by a change in the conventional cam.

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COMPARISON OF CAM CONTOURS

Fig. 2a shows the conventional while Fig. 2b shows the new cam contour. The new cam is virtually the conventional with 0.020 in. taken off the diameter of the base circle and with a tangent drawn from point A to the new base circle. The time of opening the valve is made earlier on the new cam for reasons to be shown later and in order to keep the mean valve-lift the same. The lift of the valve for the added angle is only 0.004 in. while the angular increase is 3 deg. 52 min. That is, the first part of the lift is so slow that the valve has to be given an earlier start corresponding to the backlash angle of the old cam.

As the valve-stem clearance is increased by wear the timing approaches the desired theoretical timing and then passes it, instead of always working away from it as in the conventional method. This

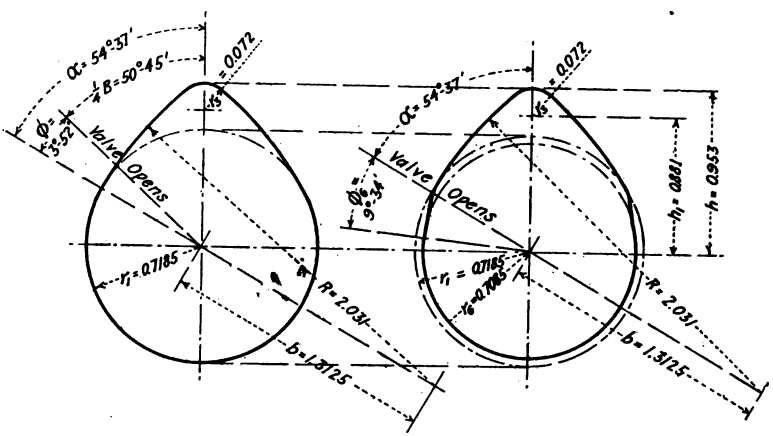

FIG. 2A—CONVENTIONAL CAM CONTOUR FIG. 2B—CONTOUR OF NEW CAM

gives the new cam a wider range to compensate for careless adjustment or neglect.

The tangent from point A to the base circle can be replaced by a curve. However, the backlash angle of the tappet will be materially increased, giving less space for the uniform base circle and thus making it inconvenient to adjust the valve stem. The action of the new cam and the defects of the old can best be explained by exhibiting the mathematical analysis in the form of characteristic curves of the cam motion. For sake of completeness the acceleration curves will also be given, although they will not be discussed.

ANALYSIS OF MUSHROOM FOLLOWER CAM MOTION

The motion of the cam will be divided into three parts for consideration. Fig. 2b shows the details of the cam. Fig. 3 shows the cam

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drawn out of scale to illustrate what will be called the "preliminary motion." This motion raises the tappet to take up the valve-stem clearance. When point A reaches the center-line of the tappet the "lower motion" begins. This continues as long as the cam-flank radius R is in contact with the tappet. The "upper motion" is that of the tappet while in contact with the cam-peak radius r_1.

Equations of the "Lower Motion"

In Fig. 4 the tappet is shown in the "lower motion," s being the space the tappet has moved corresponding to the angle θ, which the

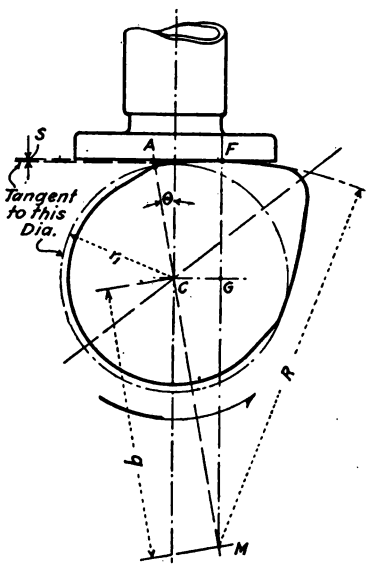

FIG. 3—"PRELIMINARY MOTION" OF CAM

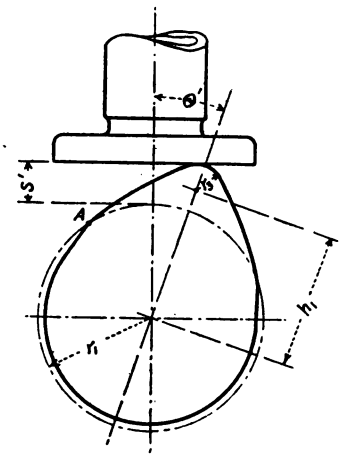

FIG. 4—"LOWER MOTION" OF CAM

cam has turned through since the point A left the tappet center-line. From right angle triangle MCG, $GF = r_1 + s$ and angle $CMG = \theta$

$$\cos\theta = \frac{MG}{MC} = \frac{R-(r_1+s)}{R-r_1}$$

$$\therefore s = (R-r_1) - (R-r_1)\cos\theta = b\,(1-\cos\theta) \qquad (1)$$

The velocity and acceleration of the tappet will be obtained from equation (1) by differentiation. The velocity is the instantaneous time rate of change of the space passed over and the acceleration is the instantaneous time rate of change in the velocity. These relations expressed by differential notations are as follows:

$$v = \frac{ds}{dt} \qquad (2)$$

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$$a = \frac{d^2s}{dt^2} = \frac{dv}{dt} \tag{3}$$

where v and a are the velocity and acceleration respectively of the tappet. Expressing θ in radians then for any constant angular velocity of the camshaft

$$\frac{d\theta}{dt} = \frac{2\pi N}{60} = \frac{\pi N}{30}$$

where N is the speed of the camshaft in revolutions per minute.

Then from equation (1)

$$v = \frac{ds}{dt} = b \sin\theta \frac{d\theta}{dt}$$

Substituting $\frac{\pi N}{30} = \frac{d\theta}{dt}$ and dividing by 12 to get the result expressed in feet since the cam dimensions will be kept in inches,

$$v = \frac{\pi}{12 \times 30} N\ b \sin\theta$$

$$= 8.73 \left(\frac{N}{1000}\right) b \sin\theta \tag{5}$$

Differentiating, equation (5) gives the acceleration in feet per second per second as

$$a = \frac{dv}{dt} \quad \frac{\pi}{12 \times 30} N\ b \cos\theta \frac{d\theta}{dt}$$

$$= \frac{\pi^2}{12 \times 30} N^2 b \cos\theta$$

$$= 914 \left(\frac{N}{1000}\right)^2 b \cos\theta \tag{6}$$

The velocity and acceleration of the valve is that of the tappet times the ratio of the valve lift to the cam lift. It must be borne in mind that equations (1), (5) and (6) only apply for values of θ falling within the "lower motion."

Equations for the "Upper Motion"

In like manner from Fig. 5 the equations of the tappet for the "upper motion" are derived.

$$s' = (r_2 - r_1) + h_1 \cos\theta' \tag{7}$$

$$v' = -8.73 \left(\frac{N}{1000}\right) h_1 \sin\theta' \tag{8}$$

$$a' = -914 \left(\frac{N}{1000}\right)^2 h_1 \cos\theta' \tag{9}$$

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where s' is the lift of the valve (in inches) after point A passes the tappet center-line, v' is the corresponding velocity in feet per second, and a' is the corresponding acceleration in feet per second per second. It should be observed that with the cam in position shown in Fig. 5, θ' is generated negatively, hence v' will be positive, since the sine of a negative angle is negative. However, a' will remain negative, because the cosine of a negative angle is positive.

It follows from Fig. 3 that the maximum value of $\theta' = \alpha - \theta_0$ and that

$$\sin \theta_0 = \frac{NL}{ML} = \frac{h_1 \sin \alpha}{R - r_3} \tag{10}$$

Equations for the "Preliminary Motion"

Again in like manner and from Fig. 3, the equations of the tappet of the "preliminary motion" are derived.

$$-s_p = r_1 (1 - \cos \theta_p) \tag{11}$$

$$v_p = -8.73 \frac{N}{1000} r_1 \sin \theta_p \tag{12}$$

$$a_p = -914 \left(\frac{N}{1000}\right)^2 r_1 \cos \theta_p \tag{13}$$

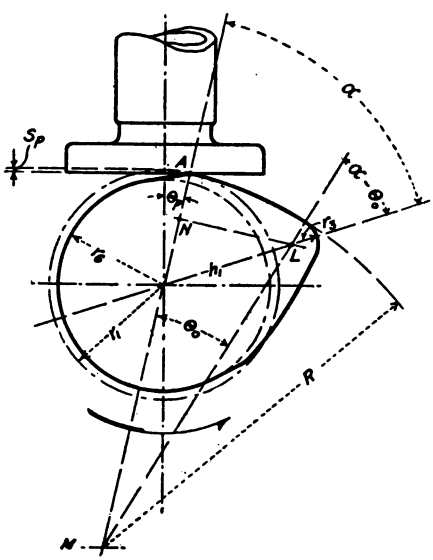

FIG. 5—"UPPER MOTION" OF CAM

where s_p is the distance of the tappet from its position when point A crosses the tappet center-line, v_p is the corresponding velocity, and a_p the corresponding acceleration.

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By means of the above equations the curves of Fig. 6 were drawn, after calculating several points for each curve within each of the three motions described.

Discussion of Cam Characteristic Curves

Imagine the cam turning counter-clockwise and just beginning to lift the tappet. This will be the starting point of the curves beginning at the left-hand side. At 3000 r.p.m. of the engine the initial velocity is 1.564 ft. per sec. In order to make this discussion applicable to any speed of the engine the velocity at any position of the

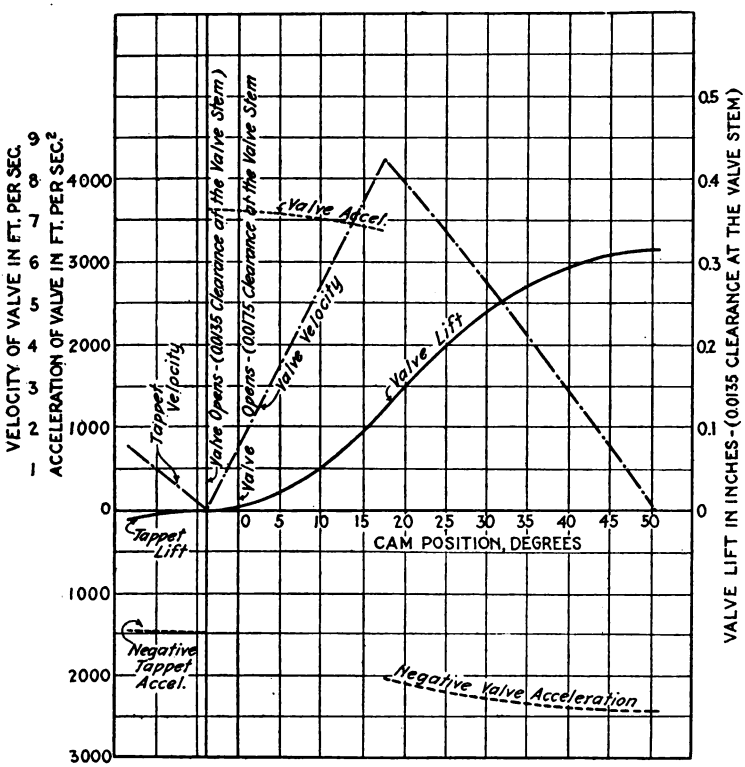

FIG. 6—CHARACTERISTIC CURVES FOR INLET CAM AT 3000 R.P.M. OF ENGINE

cam will be given as a percentage of the maximum velocity that is given to the valve at that speed. Since the maximum velocity of the valve at 3000 r.p.m. of the engine is 8.50 ft. per sec., the initial tappet velocity is $\frac{1.564}{8.50} = 18.4$ per cent of the maximum. As the cam turns farther the tappet velocity decreases until point *A*, Fig. 3, reaches the vertical center-line, when the velocity becomes zero. This

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is the end of the "preliminary motion" and at this point the tappet has raised 0.010 in., or 0.0135 in. at the valve stem. This is the position desired for the cam to begin lifting and seating the valve; the valve will then operate with zero velocity, neglecting the deflection and deformation of the camshaft and valve mechanism parts, which are distinct problems outside the scope of this paper.

As the point *A*, Fig. 3, passes the tappet center-line the "lower motion" begins. The velocity starts at zero and increases rapidly to its maximum.

As has been pointed out, point *A*, Fig. 3, is really the starting point of the backlash angle of the old cam. In order to keep the mean valve lift the same as that of the conventional cam the backlash angle of 3 deg. 52 min., is added to the old timing. The tappet raises only 0.003 in. for this angle and practically does not give a change in the desired timing as far as the actual lifting and closing of the valve is concerned.

It is at this 0.003-in. lift of the tappet, corresponding to 0.004 in. at the valve, that the old cam was designed to start opening the valve. The valve velocity at this point is $\frac{1.553}{8.50} = 18.26$ per cent of the maximum. All this is an increase over the velocity obtained by the new cam as the valve opens and is independent of the location of the camshaft or the type of engine. For our aluminum engine the above is not the worst condition when operating with the conventional cam, because the clearance of 0.004 in. is only about one-third of that required, namely, 0.0135 in.

A clearance of 0.0135 in. for the conventional cam gives a valve velocity of $\frac{2.865}{8.50}$ or 33.7 per cent of the maximum; in other words, an increase of 33.7 per cent over that of the new cam.

These velocities are so high that it was imperative to reduce them materially. In the new cam a 100 per cent reduction of these high velocities is obtained without increasing the manufacturing cost of the valve mechanism.

AUTHOR'S CONCLUSION

In an aluminum engine the valve-stem clearance must be adjusted when the engine is at its working temperature. This takes care of other inequalities, such as exhaust-valve stems expanding more than the intake and other peculiarities of expansion and contraction, which are impossible to provide for in adjustments made on a cold engine.

Furthermore, since the use of the thermostat has become practically universal the working temperature is held quite constant during the operation of the engine. This condition is taken advantage of in the new cam design; the valve-stem adjustment can be made of such an amount that the valves can be opened and closed at a cam position giving practically zero velocity at any speed.

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DISCUSSION

WM. G. WALL:—The layout shown has a rise or tangent off center on both the opening and closing sides of the cam. Probably with such a clearance as 0.013 in. it may be necessary. Has Mr. Nelson made experiments to see whether if the cam was shaped in such a way on closing side only, that is, when the valve was seating, he would not get the same degree of quietness as he does by shaping the cam this way on both the opening and closing sides? Usually the greatest noise comes from the closing valve.

A. L. NELSON:—It is quite true that the greatest noise comes from the closing of the valve. Experience with the conventional cam shows that the nearer we approach zero tappet-clearance the quieter are the results obtained. This striving for zero tappet-clearance of the conventional cam corresponds to 0.010 in. (measured at the cam) of our new cam. The corresponding velocity of the valve on closing is zero, the ideal for which we all have been striving. The shape of the cam contour after the valve has closed is unimportant as far as noise is concerned. The velocity of the moving parts is zero, their kinetic energy is zero; hence, no appreciable impacts follow to give additional noise.

WM. G. WALL:—If the rise was only on the closing side, would not the result be the same as far as quietness is concerned?

A. L. NELSON:—The results would not be as good since it is desirable to have the rocker arm strike the valve stem with zero velocity as well as to have the valve seat with zero velocity. However, in the case of our aluminum engine the additional clearance of 0.010 in. is necessarily taken off all the way around the back of the cam in order not to hold the valve open when the engine is cold. In particular cases it might be desirable to make the "preliminary motion" of the opening side of the cam different from that of the closing side since it is necessary to contend with the initial velocity of the tappet as it strikes on the opening side. This point was watched very closely in making our experiments, both as regards quietness and wear on the cam.

LEROY V. CRAM:—We have found that with zero velocity at the valve-closing point, carbon was deposited on the exhaust valves. Has Mr. Nelson had that trouble?

A. L. NELSON:—I would like to ask evidence of the zero velocity being the cause of the carbonization. We have experienced no such trouble.

LEROY V. CRAM:—With zero velocity as the valve seated we had trouble due to carbon, even on short runs. With the same engine and considerable velocity as the valve seated, carbon did not cause undue valve leakage.

A. L. NELSON:—In my paper I mentioned the fact that such problems as deflection of the camshaft and push-rod deformation would

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not be considered. These materially affect the closing velocity of the valve and are extremely important factors entering into the design of the cam layout as a whole.

A stiff camshaft having a maximum deflection of 0.002 to 0.003 in. is desired. Many camshafts have 0.010 in. deflection or more. This allows the valve to close while its velocity is a very large percentage of the maximum. The result is an extremely noisy valve mechanism. However, even with a stiff camshaft the deflection, and careless tappet adjustment as well, tends to result in valve-closing velocities different from zero.

The new type of cam works so nearly at ideal conditions of quietness that it is far more satisfactory than the conventional, yet the actual valve-closing velocities under operating conditions preclude the carbonization trouble.

I would like to ask Mr. Moskovics about the experiments in regard to the tappet clearance required for the Marmon aluminum engine.

FRED E. MOSKOVICS:—I was wondering how the roller construction would be obtained.

A. L. NELSON:—The conditions of operation of the new type of cam are even more ideal for the roller and tangential cam than for the mushroom form. This follows from the fact that the initial velocity given the tappet in the "preliminary motion" is zero. After the tappet is started the velocity increases and then decreases again to zero just as the valve is picked up.

FRED E. MOSKOVICS:—In our own case, we have had little trouble. We have held our wall temperatures very low and have used aluminum lifter rods. I think we sacrificed some efficiency in holding our general engine temperature down low, but we have not had so much variation in cylinder rods. I was surprised that neither Mr. Jehle nor Mr. Crawford brought up as a feature the fact that we do not seem able to keep the aluminum engine warm. We might have to get a heater, instead of cooler, as seems to be the problem with cast iron engines.

LEROY V. CRAM:—In working out the roller lifter, did the circular form at the toe and heel of the cam work out better than the tangential form?

A. L. NELSON:—To a large extent the type of cam used has no bearing on the cam motion derived, for it is possible to obtain the lift curves of one type of cam with another by calculating the dimensions of the cam to give a predetermined motion as desired. The only restrictions in this direction are the practical cam dimensions allowable in any case. The easiest way to duplicate cam motions is to work from the velocity curves.

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MID-WEST SECTION PAPERS

TESTING VARIABLE-SPEED ENGINES BY A NEW METHOD

By Prof. Daniel Roesch

(Member of the Society)

The present method of testing variable-speed gas engines, as used in automobiles, motorcycles, marine craft or aircraft, consists primarily of determining the *maximum* torque and horsepower at a number of different speeds. These results are plotted on coordinate

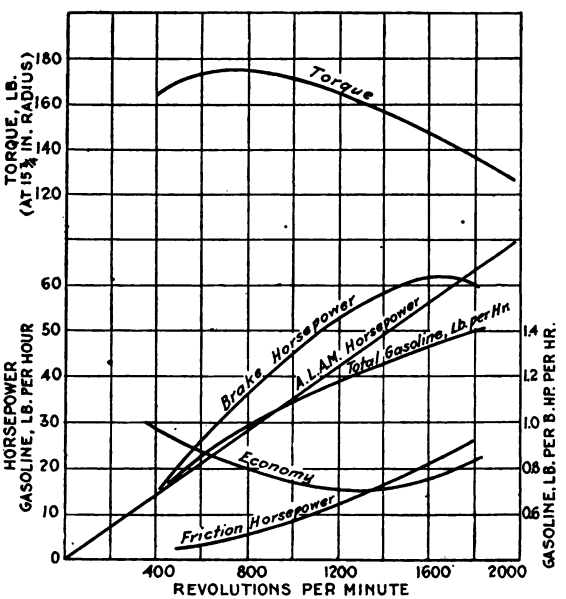

Fig. 1—Torque, Horsepower and Fuel Consumption Curves

paper; a smooth curve drawn through them represents the ultimate torque and horsepower characteristics for all speeds within the test range. The gasoline consumption is often taken simultaneously with these data. The gasoline consumption per hour or per brake horsepower per hour can then be plotted in the same way. These data are customarily taken under wide-open throttle conditions, the results

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being plotted with revolutions per minute as abscissas and the other variables as ordinates. These data and others less frequently taken during tests or derived from test results are:

(1) Revolutions per minute of the engine.
(2) Developed torque—average turning-moment developed.
(3) Brake horsepower—calculated from (1) and (2).
(4) Friction torque.
(5) Friction horsepower.
(6) Gasoline rate—preferably weight per unit of time.
(7) Gasoline economy—weight per unit of power per unit of time, calculated from (6) and (3).
(8) Jacket-water rate—preferably weight per unit of time.
(9) Sensible heat in exhaust—by calorimeter.
(10) Exhaust analysis—for incomplete combustion.
(11) Radiation—preferably obtained by difference.
(12) Air rate—weight per unit of time.
(13) Mixture ratio—calculated from (6) and (12).
(14) Depression in inlet manifold—indicating carbureter resistance.
(15) Pressure in exhaust manifold—indicating exhaust-pipe resistance.
(16) Spark advance.
(17) Mean effective pressure, net—from (2), or (1) and (3).
(18) Mean effective pressure, actual—from indicator card; from (1), from (3) and (5), or from (2) and (4).
(19) Mechanical efficiency—from (2) and (4), from (3) and (5), or from (17) and (18).
(20) Compression pressure—by indicator test.
(21) Heat balance—percentage of heat supplied appearing as:
  (a) Indicated horsepower.
    1. Brake horsepower.
    2. Friction horsepower.
  (b) Jacket-water loss.
  (c) Sensible heat of the exhaust.
  (d) Incomplete combustion.
  (e) Radiation.

These characteristics of a variable-speed engine show only its performance under wide-open throttle conditions—a condition often not maintained in use. It would follow then that an engine *A*, showing superior merits to an engine *B* under the usual test conditions, can have inferior merits when tested under partly-open throttle. This difference would have little moment where the engine operates largely at wide-open throttle, but might have a determining influence when the operation was chiefly at partly-open throttle, as in the automobile or motorcycle engine.

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PRELIMINARY INVESTIGATIONS

In order to investigate this question and develop a method of analysis for engines of this type the author suggested to Messrs. Cooban, Palmer and Stepanek, Class of 1915, Armour Institute of Technology, that they conduct a preliminary investigation of this problem as a thesis. This investigation furnished the necessary data upon which the method was developed. Additional investigations utilizing and developing this method of testing are at present being

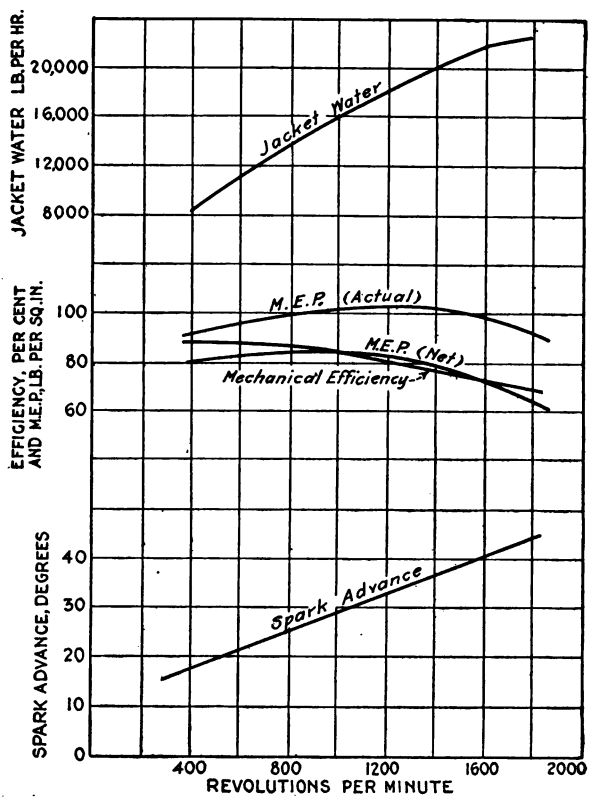

FIG. 2—CURVES FOR ENGINE OPERATING WITH WIDE-OPEN THROTTLE

conducted in the Armour Institute laboratories by Messrs. Fritze, King and White, Class of 1917.

Electric-dynamometer tests were conducted on a high-class 4 by 5½-in. six-cylinder L-head engine built about June, 1914. The data were taken so as to cover all ranges of speed and load on the engine, whereas the customary method covers all ranges of speed at maximum

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load only. The engine was new, was fitted with stock pistons and had no extra provisions for lubrication. It was deemed therefore advisable not to operate at high speed or heavy loads more than ten minutes without decreasing the load. A run confined to this time limit gave accurate readings of power and economy with possibly questionable readings of jacket losses.

Since this paper deals with the method of obtaining new test data and not the actual figures obtainable, slight inaccuracies are of no particular consequence. The test data as replotted nevertheless represent performance characteristics in a new and broader way than

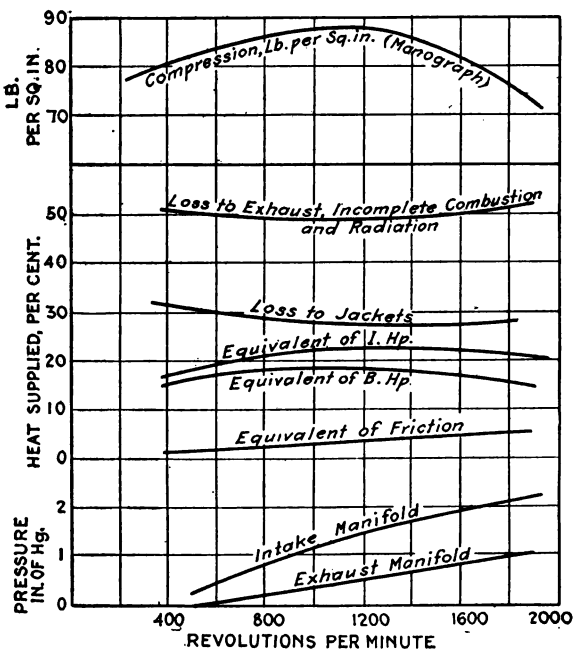

FIG. 3—CURVES SHOWING DISTRIBUTION OF HEAT SUPPLIED TO ENGINE

heretofore observed. While the 1915 preliminary thesis established that such a method gave the desired information, it was considered more cumbersome than the one here described.

If data enumerated under items (1) to (21), inclusive, were taken during a test of an engine the resultant curves might be conventionally shown as in Figs. 1 to 3, inclusive. It is to be again noted, however, that only wide-open throttle conditions of operation are represented by these curves.

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METHODS OF COMPLETE ANALYSIS

The complete analysis of an engine of the type considered can be determined from data taken in the following manner:

Tests are first made in the conventional way at various speeds with wide-open throttle. Whatever data are desired are then taken at each test speed and the customary characteristic curves plotted. One of these will be the torque curve, which is frequently taken as the pull in pounds at a 15¾-in. radius. This characteristic is represented by *A*, Fig. 4. The corresponding horsepower curve is represented by *1*, Fig. 4, and shows the maximum power developed at any speed. If now a constant torque of say, 140 lb. at 15¾-in. radius be main-

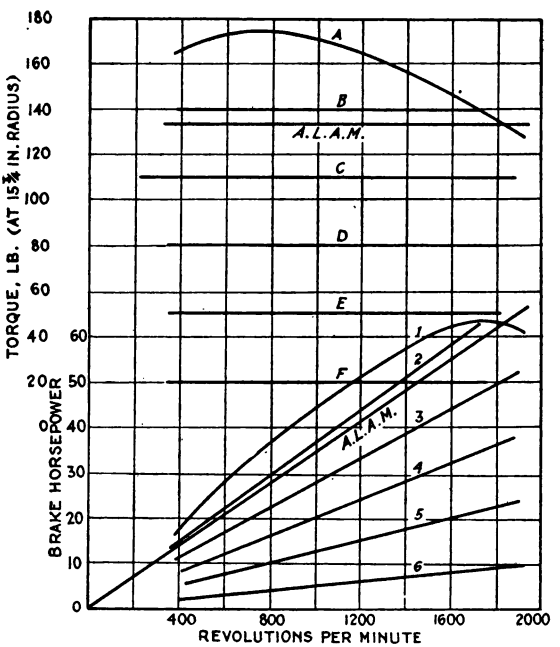

FIG. 4—HORSEPOWER CURVES FOR CONSTANT TORQUES

tained and the test conducted as before, we can obtain torque curve *B*, Fig. 4, and the corresponding horsepower curve *2*. Similarly the curves *C*, *D*, *E* and *F*, and their respective horsepower curves *3*, *4*, *5* and *6* are obtained for various constant values of torque.

Whenever the torque line is horizontal a constant mean effective-pressure, net, has been maintained by the engine; also the horsepower increases directly with the speed. This is similar to the N. A. A. M. horsepower rating and its corresponding mean effective-pressure, net.

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These lines are added to Fig. 4 for comparison. Since the horsepower of all but the first series of tests is proportional to the speed these curves will be straight lines and pass through the intersection of the axes.

Instead of selecting constant even-value torques for lines *B*, *C*, *D*, *E* and *F*, an alternative method would be to obtain these curves so that they would correspond to 67.3 lb. m.e.p., net, and say 15, 30, 45, 60, 75 and 90 lb. m.e.p., net. The advantage would be in subjecting various engines to like net mean effective pressures for each series of tests. This would facilitate comparison of performances. The disadvantage lies in having an odd value for the torque, which may be confusing during testing.

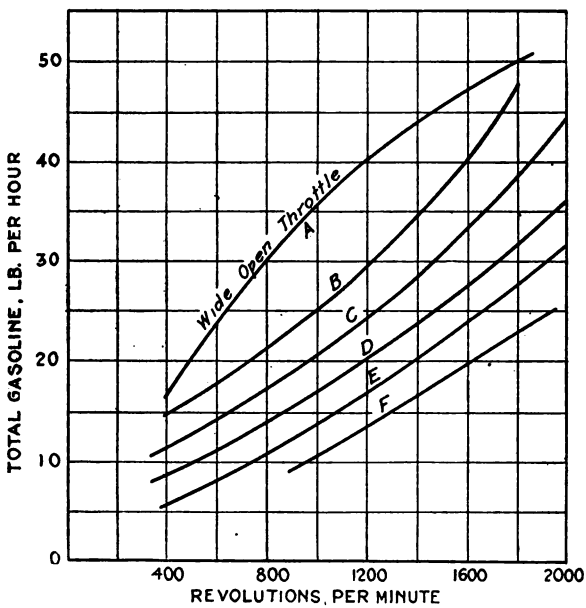

FIG. 5—TOTAL FUEL-CONSUMPTION CURVES FOR CONSTANT TORQUES

While this analysis can be applied to all of the data enumerated at the beginning of this paper, the factors of fuel consumption, mechanical efficiency and spark advance are probably the most important. The method of determining these and other characteristics under all conditions of load and speed will be indicated.

OBTAINING CONTOUR LINES

The total fuel-consumption curves for conditions as indicated, curves *A*, *B*, *C*, *D*, *E* and *F*, Fig. 4, are shown by curves similarly

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marked in Fig. 5. The gasoline consumption in pounds per brake horsepower per hour for each load condition was also computed and plotted in Fig. 6. These curves then furnish the necessary data to

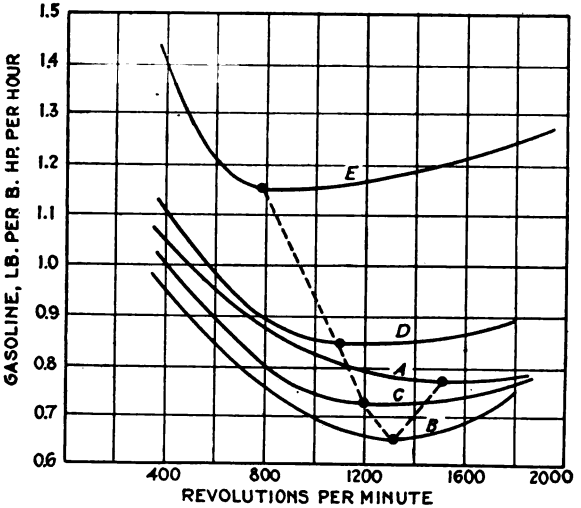

FIG. 6—CURVES OF FUEL CONSUMPTION PER BRAKE HORSEPOWER PER HOUR FOR CONSTANT TORQUES

establish the load and speed for any particular gasoline consumption. A set of interpolation curves was then constructed for 400, 600, 800, 1000, 1200, 1400, 1600 and 1800 r.p.m. with brake horsepower as

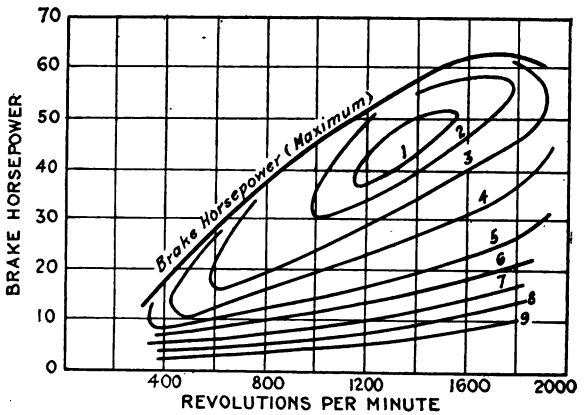

FIG. 7—LINES OF EQUAL THERMAL EFFICIENCY

abscissas and gasoline consumption in pounds per brake horsepower per hour as ordinates. The data for these curves were taken from

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the curves in Fig. 6. These interpolation curves furnished sufficient points for, say, 0.7 lb. per brake horsepower per hour, to locate properly this contour line in Fig. 7. The other lines of equal thermal efficiency were plotted in a similar manner from the same interpola-

Line No.	1	2	3	4	5	6	7	8	9
Gasoline, lb. per b. hp. per hour	0.66	0.7	0.8	0.9	1.0	1.25	1.5	2.0	2.5
Thermal efficiency on b. hp.	19.3	18.2	15.9	14.1	12.7	10.2	8.5	6.4	5.1

tion curves. Lines of equal gasoline consumption were thus established from these test data, as shown in Fig. 7. Lines of equal spark advance, Fig. 8, have been determined in a similar manner. Lines of equal mechanical efficiency, Fig. 9, have been determined by the con-

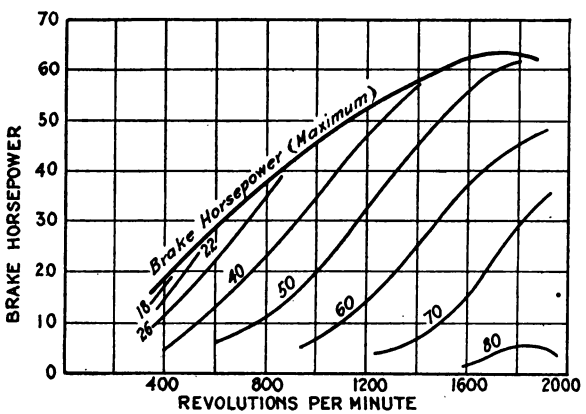

FIG. 8—LINES OF EQUAL SPARK ADVANCE

ventional electric dynamometer method. There appears to be no reason why any of the other test data ever taken could not be graphically shown in a similar manner.

SUMMARY

The chief advantage of the data presented graphically in the manner indicated is that they show concisely and clearly the performance of the engine under every possible condition of load and speed. Academically the method has already been found valuable in disclosing completely the various engine characteristics. Commercially the determination of certain of the contour lines has been found valuable in design study of the engine features affecting them.

The gasoline-economy contour curves of various carbureters on the same engine should be of particular value for purposes of comparison. The same curves from different engines would be of value in more closely predicting car mileage per unit of fuel consumption.

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The data on sensible heat in the exhaust should be of value in the design of kerosene carbureting devices, with which considerable heat is required for fuel and air preheating.

The jacket-water rate and loss should be of value in pump and radiator design.

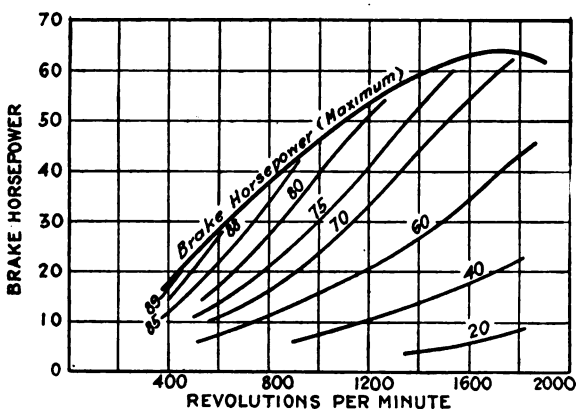

FIG. 9—LINES OF EQUAL MECHANICAL EFFICIENCY (BRAKE HORSEPOWER METHOD)

The spark-advance contour curves are valuable in design of automatic spark-advance mechanisms, which advance the spark the correct amount for load and speed variations.

No doubt many other applications of test data recorded as indicated will become apparent upon study by the automobile-design specialist.

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THE FUEL QUESTION—FROM THE DRIVER'S VIEWPOINT

By F. C. Mock
(Member of the Society)

It had been suggested that this paper discuss this subject from the standpoint of the carbureter engineer. It has been a peculiar development of automobile use, that the carbureter builder is held continuously and directly responsible for the performance of his product, on whatever car it is placed, and his viewpoint is therefore closely that of the car owner. And since the ordinary driver's requirements of car performance are sometimes different from those of the automobile designer, a consideration from the former's viewpoint should be of definite value.

In the relatively short time of development of the automobile there have been many and marked changes in the fuel used. In the early days, from 1902 to 1905, there was no fuel problem; gasoline was a by-product and so volatile that it only required proper metering with air to give efficient performance; with a normal running mixture the engines would start, cold, on the second or third half turn of the crank.

It was about 1907 that we began to have some difficulty starting with the hand crank, and to find it necessary to make the mixture adjustment a little richer for easy starting. A short while later we began to notice that an engine would not run quite the same cold as it would after it warmed up a bit. About 1909 it began to be evident that there was something in the engine that seemed to demand a graduation of the mixture. Power and flexibility seemed to demand more gasoline in the mixture than was necessary simply to keep the engine running smoothly. We began at this time to have definitely more trouble with carbon in the cylinders. There was not much difficulty with intake manifold design until we commenced to use more than four cylinders. About this time it became common to water-jacket the carbureters.

By 1912 the fuel had grown so much heavier that the self-starter was a necessary feature. Practically all carbureters were fitted with some special device for giving a richer mixture for starting. Although the carbureter makers had now practically solved the problem of producing a uniform mixture it was found that this was by no means sufficient to make the engine run, and they began to develop devices for graduating the mixture according to the evaporating conditions

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in the intake manifold. For instance, means of making the high speed mixture richer than the low speed by the use of separate adjustments and of devices for giving more gasoline on acceleration. At this time we began to have marked difficulty in making the cars run properly in the winter time. We felt that this difficulty was not due to a defect in the carbureter, although the public generally did not agree with us.

The fuel conditions during 1915 and 1916 are recent in our memory. About this time the gasoline began to contain elements boiling above 360 deg. fahr. and nearly everyone commenced to have trouble with gasoline getting into the crankcase, thinning out the lubricating oil and cutting the bearings. These years also marked the beginning of a period when the automobiling public and automobile engineers generally began to appreciate the difficulties under which the carbureter men had been working. The importance of this subject became more fully appreciated and in the last few months there has been a great deal of improvement in the design of intake systems. Practically all new intake manifolds are hot-water jacketed or have the exhaust heat on some portions of their surface, while practically all carbureter installations provide for a warm air supply.

Unfortunately these improvements are difficult to apply to engines already built, and many cars four or five years old, in the best of shape mechanically, are unusable through six months of the year because they cannot handle the present fuel.

The fuel situation in the country as a whole is further confused, because of the variation in quality. In some localities the gasoline is as good as that used say in Chicago fourteen years ago; in other places it is similar to that used there ten years ago. The variation is so great that one single design of fuel intake system can rarely give good operation in all parts of the country.

ESSENTIAL PROPERTIES OF AUTOMOBILE FUEL

These differences in operation are not due to any deficiency in thermal energy, because all these gasolines have nearly the same calorific value, but rather to a deficiency in volatility, which interferes with the method by which they are delivered to the firing chamber of the engine.

The force that drives the pistons of our engines is derived from the combustion of the oxygen of the air charge in combination with hydrocarbon vapor generated from the gasoline. The air is drawn into the cylinders by the suction stroke of the piston, from a common passage or manifold, while the gasoline is sprayed into this incoming air, at a chamber at the manifold entrance, which chamber we call the carbureter. Such parts of the gasoline as are sufficiently volatile evaporate into vapor and enter the cylinder along with the air. These volatile parts composed about 100 per cent of the early gasoline, but this percentage has diminished until now, with our Mid-West fuels,

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only about 40 per cent can be evaporated under the average operating temperatures.

The disposition of the unevaporated part of the gasoline depends on the velocity of the air carrying it, also upon the nature of the path along which the air must travel and, to a slight degree, upon the fineness of atomization of the gasoline drops. When the drops are small

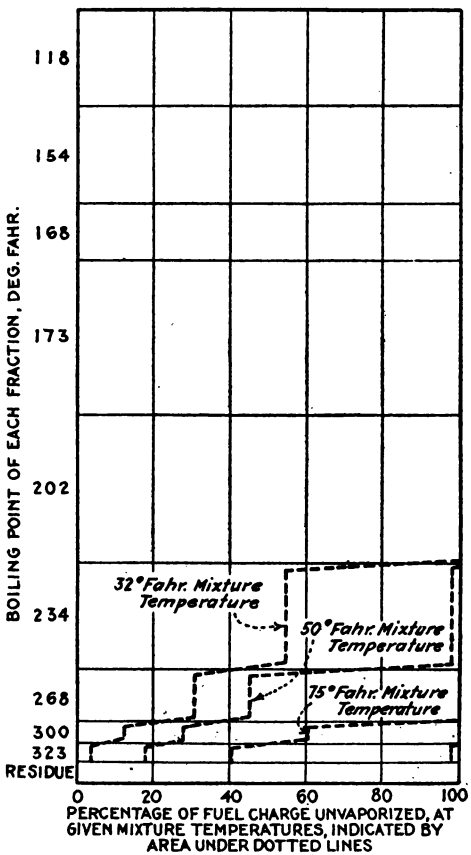

FIG. 1—COMPOSITION OF 72-DEG. B. "STRAIGHT" GASOLINE, PARAFFIN BASE—FROM PENNSYLVANIA DISTRICT

and the air velocity is about 20 ft. per sec., they are carried in suspension along with the air so that the effect is practically the same as if the gasoline were evaporated. When the velocity is lower than this, it is much easier for the drops to fall out. This collection or condensation is facilitated when there is a tee-bend or an elbow in the manifold; the gasoline particles naturally proceed in their initial

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direction of motion until forcibly deflected from it by the wall on which they strike. As soon as the drops strike the wetted wall they are subject to surface tension and from then on they cling to the wall of the intake manifold and pass along in a stream. If the air velocity at the bend is sufficiently high, about 50 ft. per sec., it will wipe much of this liquid part off the walls again and carry it along with the air.

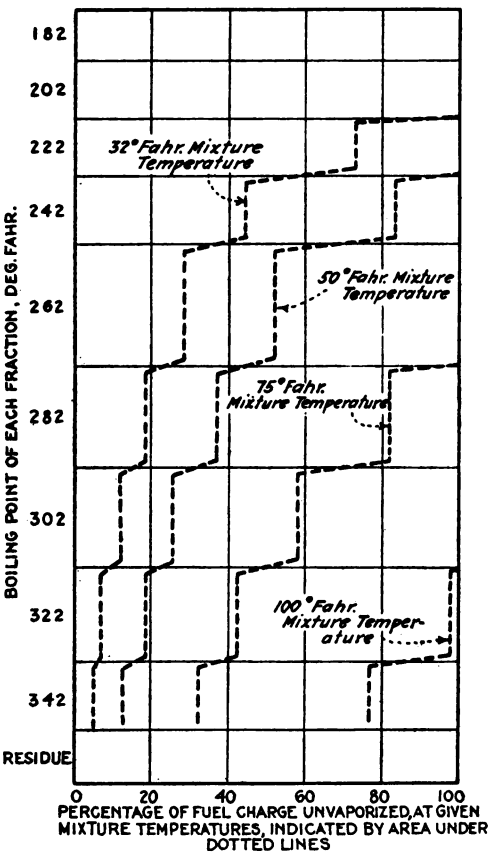

FIG. 2—COMPOSITION OF 56-DEG. B. GASOLINE USED IN MID-WEST AUTOMOBILE MANUFACTURING SECTION—MAINLY PARAFFIN BASE

Whenever the gasoline is carried in suspension with the air, it is easy to get good operation with any of our gasoline fuels. When the gasoline is not carried by the air we have trouble. For engines that run at a constant speed it is easy to design the intake manifold

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to have the requisite air velocity at that speed. With an automobile engine, however, the air velocity at the highest speed is about twenty times that at idling speed, and it is impossible to select an intake manifold size that will be equally efficient under all conditions.

WHAT GASOLINE ACTUALLY IS

"Gasoline" is not a liquid of fixed and inflexible composition such as water or benzol, but is more nearly a trade name applied to what-

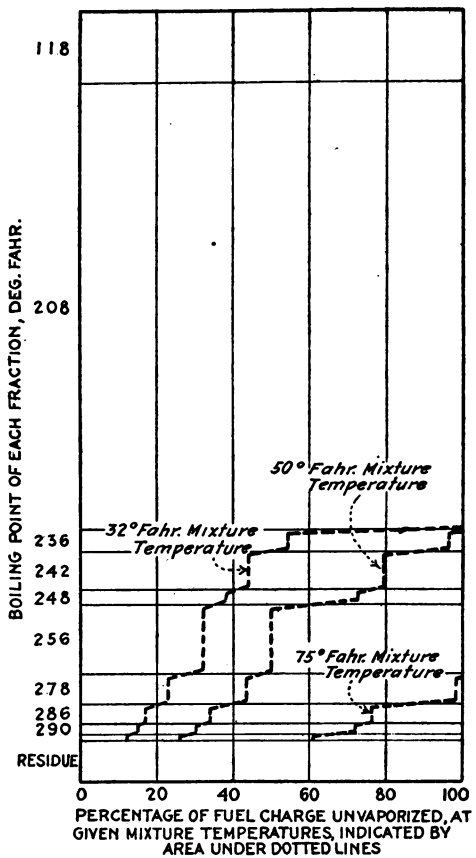

FIG. 3—COMPOSITION OF 60-DEG. B. GASOLINE; ASPHALT BASE, FROM CALIFORNIA DISTRICT

ever components obtained in the refinement of crude petroleum as are deemed possible to use as an automobile fuel. The crude petroleums obtained in different parts of the world are greatly different and this difference extends to the composition of the gasoline derived from

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them. For instance, our eastern Pennsylvania gasolines are supposed to contain mainly hydrocarbon elements of the hexane series, C_nH_{2n+2}. The gasolines found in the West and South contain elements of the following different series, C_nH_n, C_nH_{2n-2}, C_nH_{2n-4}, as well as many others. When the heavier products are "cracked" to make lighter ones, still further variety is found. All these however are capable of complete combustion in an automobile engine if properly vaporized, and further have nearly the same number of heat units per pound.

On account of the extreme difficulty of accurate chemical analysis it is common to judge the composition of these fuels by the process of progressive distillation. A measured quantity of the gasoline to be tested is put into a flask and heated. As the temperature rises a point is reached when the liquid begins to boil. The boiling continues, with nearly stationary temperature, until all of the elements

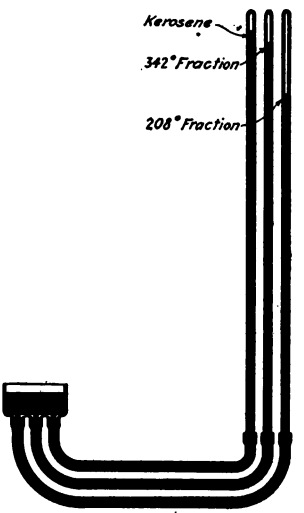

FIG. 4—TUBES SHOWING EFFECT OF VAPOR TENSION

that boil at that temperature have been converted into vapor, which is conducted away from the flask and collected in a condenser where the quantity can be measured. If the temperature is then raised another boiling point will be found and another portion distilled off, and so on.

Figs. 1, 2 and 3 show the proportions distilled off at different temperatures in three samples, which are typical of the fuel commonly used in different sections of this country. The diagrams have been made in such a form that they can be conceived as representing what would happen in a barrel of gasoline if it were possible to separate

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the elements according to gravity. The lighter elements are at the top, the lower ones at the bottom and the included area represents the relative volume of each present. It will be noticed that the Eastern gasoline and the Mid-West gasoline are quite closely graded as to the percentage of each element present, while the Western gasoline contains an extremely large percentage of the element that boils at about 280 deg. fahr.

The exact boiling point and the exact proportion boiling off at each temperature are difficult to measure, because the values obtained vary greatly according to the speed with which the distillation is conducted and the nature of the apparatus. In making these distillations we endeavored to rise from one boiling point to another as quickly as possible, but held the boiling points.

A carbureter adjusted for Mid-West gasoline will operate very satisfactorily with 72 deg. Eastern gasoline. For some reason the Western gasoline (I understand that the Texas and South-Western gasoline is about the same as this) does not operate nearly as well and requires an entirely different carbureter adjustment.

The percentage of gasoline evaporated and its rate of evaporation further depend greatly upon the position of the throttle, or, more specifically, vary closely with the vacuum in the intake manifold.

VAPOR TENSION APPARATUS

Fig. 4 shows an apparatus of the kind commonly used to demonstrate vapor tensions, consisting of three glass tubes connected to a common mercury vessel. The upper ends of the tubes are sealed, and contain nothing above the mercury but liquid gasoline and vapor. In one tube is shown the 208 deg. fahr. fraction obtained from the California gasoline whose distillation fractions are shown in Fig. 3. The second tube shows the 342 deg. fahr. fraction taken from our Mid-West gasoline, while the third tube contains common kerosene.

If this gasoline or kerosene were not present, these tubes would be simply barometers and would remain absolutely full of mercury until the level of the mercury in the vessel was lowered more than 29½ in. below the top of the tube. If the vessel was lowered farther than this the mercury would follow the lowering of the vessel to show the atmospheric pressure in this room, and there would be an absolute vacuum above the mercury.

The space that now exists above the mercury in the tubes is filled by a small portion of liquid gasoline and by the gasoline or kerosene vapor from it. The space occupied by the vapor of the 208 deg. fraction is about three times as great as that occupied by the kerosene vapor, while the space occupied by the 342 deg. fraction is about 20 per cent greater than that occupied by the kerosene vapor; this indicates the great difference in vapor pressure and density that accompanies the difference in boiling point of the gasoline elements.

The heating of the upper part of the tubes to a temperature of

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about 120 deg. fahr. causes the space occupied by each vapor to increase to nearly twice that occupied at the room temperature of about 72 deg. With this increase the amount of liquid gasoline above the mercury will decrease perceptibly, showing that more has been evaporated.

SPACE AND TIME FACTORS IN EVAPORATION

There are two very important points that can be shown with this apparatus. As the mercury vessel is raised and lowered, the level in the tubes keeps the same distance above the level in the vessel; but although the vapor pressure or tension remains the same when the mercury is lowered to give more space in the tube, the amount of vapor increases with the volume of this space. This is shown by the decrease in quantity of liquid gasoline standing above the mercury column. For instance, if the mercury is lowered until a 12-in. space is shown in the 208 deg. gasoline tube, the liquid gasoline evaporates altogether. This corresponds to the change of conditions that we have in our intake manifolds when the throttle is opened. At any given engine speed, as we close the throttle we feed *less* gasoline, but we leave the *same space* for the vapor to occupy, with the result that a much greater percentage of the gasoline can be converted into vapor during the closed-throttle condition. This fact, in conjunction with the preceding ones, gives the reason why we have difficulty in handling our present-day heavy fuels *at wide-open throttle and low air-velocity.*

The second point of importance is that when the mercury is lowered to allow room for the increased evaporation, the change in state occurs *at once.* Within a second the gasoline evaporates to fill the space available. This shows, what we have believed from experience, that the predominating factors in determining the actual evaporation of gasoline in the intake manifold are the *vapor tension of the various elements* and the *temperature,* and that we *do not have to allow time for the gasoline to evaporate;* in other words, the gasoline evaporates, as much as it can, almost immediately upon passing the throttle.

In recent years we have helped engine operation by preheating the air charge or by heating the intake manifold, but the heavy elements introduced into the gasoline lately are so non-volatile that their complete evaporation requires heating the manifold and entering air *above the boiling point of water,* and to so high a temperature that the amount of air charge, and consequently the power of the engine, is perceptibly reduced.

In some recent experiments we directed an atomized supply of gasoline into a bent elbow, through which air was being drawn, and noted the condition of the issuing mixture when the elbow was heated at different temperatures. Although the spray was very fine indeed, so that it would change into a mist and then disappear when the jet was directed into the air of the room, in the elbow the action was very

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bad. The gasoline would strike on the far wall of the bend and drain back out of the elbow in a steady stream, while only a few particles would issue from the mouth of the elbow. This was at temperatures of the elbow from 70 to about 220 deg., with the entering air at about 70 deg. When the elbow was heated to about 250 deg. conditions were somewhat better, as about two-thirds of the gasoline drops seemed to pass the bend without condensing on the wall and there was consequently less "loading" in the elbow. When the elbow was heated to 310 deg. there was no condensation whatever and the gasoline came out of the elbow in a white smoke or dry fog.

NECESSITY FOR COMPROMISE IN ENGINE DESIGN

In developing an automobile engine of the type used today it seems necessary in order to use fuel no heavier than that we now have to choose some sort of compromise among: (1) Restricting the torque at high speeds by a small intake manifold; (2) heating the charge so much that the power is reduced; (3) reducing the range of operation (that is, providing a range of operation of from 5 to 45 m.p.h. at wide-open throttle instead of from 1 to 60 m.p.h.); or (4) using light gasoline, which is now expensive, and will become more so in years to come.

Just here it is of value to consider the subject from the driver's viewpoint. Many engineers would rather do anything else than sacrifice maximum power per cubic inch of piston displacement, which is not a satisfactory rating of the power of the engine in the car, because it applies to but one speed, and that one seldom used. This "maximum power" is extremely different from the maximum power the driver knows, which is usually gaged in the way it is most usually employed, by the torque available for acceleration at ordinary driving speeds. The automobilist also objects to paying a high price for gasoline, or having to go to special filling stations to get a particular kind. I further believe that the average man is willing to shift gears when it is necessary to pull through sand or climb a hill below 7 m.p.h.; in fact, he should do so for mechanical considerations alone. To practically every driver it is of much more importance than are many well-known mechanical "talking points," that a car should warm up to a temperature of good running in a few blocks, yet how few are the cars that will do this. There are many similarly logical reasons why, with the fuel situation as it is, we should be prepared to yield some standards of performance in order to realize certain other standards of economical and convenient operation.

PROPER GASOLINE SPECIFICATIONS

There are also different viewpoints on the fuel proposition. The oil men, and they have perhaps the economically correct view, wish to use as many heavy elements as possible. The automobile engineer

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wishes to secure the best performance possible. The automobilist does not care so much about the fancy details of performance; he does want to get his fuel at the lowest price possible, yet he wishes to avoid trouble from gasoline in the crankcase and excessive carbon deposit.

It seems to me that all this must depend primarily upon the design and efficiency of the engine in which the fuel is to be used. If the engine is one of an older design it is necessary to use a light grade of gasoline, because it simply will not perform properly with any other. With engines of the present design we can almost use satisfactorily our better grade Mid-West gasoline, provided we make a few practical allowances. It is possible that we can develop further our engine and thus allow us to use still heavier fuels. I am very sure however that we cannot use heavier fuels than the engine will stand without great trouble in average use. For instance, a great deal of gasoline sold contains a perceptible amount of kerosene. With the average carbureter on the average car one to three years old, the driver would be much better off, get better service and equal mileage for his money if after buying this gasoline he could separate, remove and throw away this kerosene fraction. It does no good and does do harm.

In the face of conditions such as I have described, it is impossible to set any definite limit or requirement for gasoline standards. I believe however that if we adopt any convenient standard of graduation, the situation will solve itself on an economic basis, as each automobilist will buy the cheapest grade of fuel that he can use. When he buys a new car he will naturally select one that will handle the heavier fuels. This will make it a definite object for the car manufacturer to use a heavier fuel and will promote this development faster than in any other way.

USE OF HEAVIER FUELS

Until a very short time ago we had not seen in operation any system that would use kerosene without there being so many disadvantages that it gave no promise for automobile use. In fact, kerosene is scarcely satisfactory even on engines running at constant speed, where there is no limitation as to intake air velocity or as to the amount of heat available. We have recently found by following a cycle whereby the kerosene is vaporized at a very high temperature, and then mixed with a charge of air at low temperature, that the resulting fog can be kept in complete suspension in the air stream. This should do away with the troubles previously described, so far as they relate to conduction of the fuel to the cylinders. There remains the further difficulty of obtaining a vapor in the cylinders, so that the spark can be carried away from the spark-plug points. Such trouble can probably be overcome by mixing the kerosene with some of the elements now found in gasoline; this is also desirable as a step toward economical use of our fuel resources, because such a blend corresponds more nearly with the composition of the natural petroleum product.

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DISCUSSION

DR. WM. M. BURTON:—Several articles, bearing on automobile fuels, have been published recently in current periodicals. For example, in the March number of *Oildom*, page 116, we find a somewhat extended article entitled The Gasoline Situation Threatening. Also, in the February number of *Petroleum Age*, page 3, appears an article by Chas. V. Bacon, entitled Gasoline—Analyses and Interpretations. Further, in the March issue of the *National Petroleum News* Dr. W. F. Rittman presents an article bearing upon the past and present of the gasoline situation and also making some predictions regarding the future. These articles appear to contain no extravagant statements or statements that are not in harmony with the facts.

In Mr. Bacon's article methods of making fractional distillations are described; these seem to be logical and would conform to the best methods accepted by the industry. He also describes experiences with twenty different samples of gasoline produced by as many different refiners and dealers. He has very little criticism to make of the quality of the gasoline being used, or of its behavior in internal combustion engines. I think it is the experience of every dealer in gasoline that a certain percentage of complaints can be expected from the users of motor vehicles. Defective ignition apparatus, or defective carbureters, or improper adjustments cause faulty workings of machines and, in the majority of instances, the blame is all laid upon the gasoline, regardless of where the fault actually lies. I think however we can conclude that the bulk of the gasoline now used is reasonably satisfactory, that its quality in future will probably not change materially from that which is on the market at present, and that we can concern ourselves principally with the future in regard to the supply of this indispensable fuel.

During the past ten years, since the automobile and internal combustion engines have become such prominent factors in the economic conditions of this country, the number of machines in the United States has increased from 250,000 in 1907 to an estimated number of 4,000,000 in 1917. The gasoline production has increased in that period from around 400,000,000 gal. in 1907 to an estimated production of over 2,000,000,000 gal. in 1916.

The question might well be asked why the increase in gasoline production has been 400 per cent during the past ten years, whereas the increase in the number of automobiles has been over 1000 per cent. Ten years ago a large quantity of gasoline was consumed in this country in "gasoline stoves," widely used for domestic purposes. Today the gasoline stove has become almost extinct and thus a considerable quantity of gasoline has been released for use in internal combustion engines. But for this extenuating feature the situation would undoubtedly be much more critical today than it is.

During this ten-year period the production of crude petroleum has not been correspondingly increased. It is estimated that 2,500,-

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000,000 gal. of gasoline will be produced in this country during the year 1917. Allowing 500 gal. per year for each motor vehicle, and estimating 4,000,000 motor vehicles in service, the consumption for these vehicles, alone, would be 2,000,000,000 gal. for the year 1917, leaving only 500,000,000 gal. for export and for use in other types of internal combustion engines.

Unfortunately, the production of crude petroleum is not increasing in anything like this proportion. There are but two inevitable conclusions: first, the yield of gasoline or engine fuel from crude petroleum must be tremendously increased, to meet the increasing number of internal combustion engines made; or, second, the rate of increase in the manufacture of these internal combustion engines must be lessened.

A considerable increase in the yield of engine fuel from crude oil has been secured during the past three or four years by improved refining processes, but, owing to the inability of the refiners to secure necessary steel and other supplies for building stills, it is not at all probable that the increased production of engine fuel will meet the tremendous increase indicated in the manufacture and sale of motor-vehicle and other internal combustion engines. It is also not probable that the production of crude petroleum will increase in the near future to any substantial extent.

Much good could be accomplished by a campaign of conservation and economy in the use of the indispensable gasoline. Much of it is wasted in the running of cars. Automobile engines are allowed to run while cars are standing, and a campaign of economy along this line would be beneficial.

The refiners throughout the country are doing all in their power to secure the largest possible yield from crude petroleum, but much still remains to be accomplished along this line of conservation, and more would have been accomplished today had not the European war interfered with the construction of improved and additional equipment.

In this brief discussion I have brought out no new matter, but have attempted rather to emphasize and reiterate what has already been presented to the public through various papers printed in current periodicals. I desire to add a word of warning to the manufacturers of internal combustion engines, that the time may come when we will have more of such machines than we will have fuel to supply them.

FRED C. GLOVER:—We have a number of tractors down in Cuba burning alcohol, or rather they were burning alcohol before the war. They were distilling alcohol on the larger plantations for eight cents a gallon and they insisted on having all their stationary engines and tractors equipped to burn alcohol. They have proved very satisfactory to operate. We have much less trouble in burning alcohol than with gasoline. There is no carbon and by raising the compression we have gotten fairly good economy. But at the low cost alcohol is much more economical and a much more satisfactory fuel to work with than either gasoline or kerosene.

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Congressman Marsh, who introduced a denatured alcohol bill into Congress some years ago, looked into the matter thoroughly, and found that in Germany alcohol was being made without Government restriction for from twelve to fifteen cents a gallon, while in Cuba the cost was eight to ten cents a gallon.

DAVID BEECROFT:—The possible market in Argentina and Brazil for tractors and heavy trucks, and even for large automobiles, is much curtailed because of the fuel situation. In Brazil and in parts of Argentina gasoline costs fifty to seventy cents a gallon, and a great many tractors were idle. Unfortunately in Argentina the Government prohibited the use of alcohol except under certain restrictions. They were exporting a good deal, but it was imposible to get legislation that would permit its freer use as a fuel. It was very generally thought there, however, that they would eventually have to look to alcohol for this work.

The Argentine Government has had a good deal of correspondence with Washington with the thought of seeing to what extent alcohol is used in this country. The feeling there was that they would have to use alcohol; being a great agricultural country similar to our Mississippi Valley, there is no reason why they have not all the chances in the world of growing the different crops that would produce alcohol and give it at a reasonably low price.

The farm-tractor movement in Argentina has been held back a great deal owing to the lack of farm mechanics competent to give the necessary attention to the tractors already sold. No country in the world is better situated for the tractor than Argentina, but unfortunately the scarcity of fuel and lack of mechanics gave a severe setback to the industry. The present poor crops have further aided this depression. But interest is increasing in the small tractor and the sale of automobiles to the farming community is developing the spirit of mechanics, which should assist tractor sales. A few good crops and a big recuperation in the tractor industry would take place.

DR. H. C. DICKINSON:—I am here as a member of the joint committee of the Bureau of Standards and Bureau of Mines, appointed sometime ago to look into the question of the standardization of gasoline. This committee has not considered directly the alcohol question. The committee has had several general meetings at which there was a large representation of oil producers and jobbers, and a very small representation from the automobile industries, which seemed unfortunate. The work of the committee was undertaken on the request of individuals and of some of the automobile interests, and we would like to have more support from this side. While recommendations are not yet in final form the committee has definitely decided to recommend a procedure somewhat along the lines that Mr. Mock has suggested. I do not know that I agree entirely with Mr. Mock as to the availability of tests based on the method of distillation. The distillation test for other purposes, for instance for the standardization of

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turpentine substitutes, which are gasolines of a little bit poorer quality than gasoline for engines, gave satisfactory results, and we know that with a proper standardization of method of distillation the distillation test will give satisfactory results with gasoline.

This committee is likely to recommend a requirement that certain qualifications of gasoline be made a part of the label in the sale of product. It is probable that the requirements will be something like this: A certain temperature at which a certain part, perhaps 20 per cent, of the fuel will evaporate, and another temperature at which a percentage, probably 90 or 95, will evaporate, with two or three minor qualifications, that will not necessarily appear. Now that would require that all accepted automobile fuels be sold with a label bearing two figures, one a figure that would indicate the temperature at which a lower percentage would evaporate, which is of interest in starting the engine cold, and the other a figure at which substantially all of the fuel will evaporate; this will be of interest in determining the inlet manifold design necessary to obtain complete vaporization.

H. L. HORNING:—I agree with Dr. Dickinson that the distillation test Mr. Mock mentions is not unsatisfactory. We have found it very satisfactory. We have taken samples of gasoline and sent them to the Bureau of Mines and had a test made there, have made a test ourselves and have found that the result varied by only one or two degrees, which is very small, at both ends of the scale. It is the consensus of opinion that the volatile test is the only test on which gasoline can be measured, the only scale by which it can be judged. Inasmuch as that probably will be the method in the future of measuring the value of gasoline, it is particularly interesting to know that it is reliable. One of the men in our experimental laboratory had seen us make these tests, but had not taken part in them himself.

One day I told him to make a distillation test. He came back with a grotesque distillation report, and I thought that there had been a mistake. I asked him how fast he had run it and he said he had shoved it just as fast as it would go. I told him to try it at two drops a second and he did, but he made a mistake in that. He did it a third time and it was correct; his report could be checked the next day by the distillation test of someone else. His second test was wrong, simply because the door was open and it blew the flame that was heating the kerosene in the flask. It is just merely a matter of maintaining conditions in order to make the distillation test a valuable one.

HERBERT CHASE:—I think greater attention should be paid to developing an engine for the use of heavier fuels. In Europe there is now at least one tractor and I believe several others under way in which a semi-Diesel type of engine is used successfully. We are hearing about the probability of a return to the steam engine in tractor work and a partial return in the automobile field, and the real reason

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for that is that a heavier fuel than gasoline can be used. The steam engine has certain characteristics that make it better adapted to vehicle propulsion than the ordinary gasoline engine. While it is most important to consider the problem of today in reference to the use of fuel that we can burn in the gasoline stage, we should not lose sight of the fact that in the future we must use heavier fuel than is now available. We should begin to think about using it in a practical way, both for automobile, tractor and motor-boat service.

FREDERICK PURDY:—One part of the subject that is seldom mentioned is the increasing difficulty due to the difference in the specific gravity of the air and the fuel. The difficulties attending the evaporation are better known than the means for doing it.

There is difficulty in accelerating when the fuels are very heavy. When the fuel is evaporated by any means it is more responsive to the impulse of the air stream. The tendency of any body is to continue in a straight line after a force has been impressed upon it and to maintain any speed with which it is impressed; the heavier the body why of course the more sluggish is its response to change. The entire air content of the manifold is naturally responsive at once to any changes due to the opening of the throttle, whereas the heavy fuel content is sluggish. It lags behind and it is due to this difference that we have difficulty now in accelerating the engine.

If we heat the fuel enough so that acceleration is secured automatically by the fuel itself and not by any mechanism within the carbureter, we have probably expanded our charge to such an extent that the efficiency of the engine is greatly diminished, that is the efficiency per unit of volume. That, of course, would mean larger engines and that we can hardly submit to. The engines are large enough now for the little jobs they are required to do.

I would like to think of alcohol as a fuel. It solves a good many of our problems. It would to a large extent solve the acceleration problem, because we shall have in it a fuel that will evaporate completely and when it is evaporated completely it will respond very well to the impulse of the air stream and a large proportion of the fuel will not lag behind, thus thinning the mixture when the throttle is suddenly opened.

The difficulties in the use of alcohol are perhaps not so great as we who have been making carbureters for petroleum fuels have been led to believe. We do not like to use alcohol because we think we have to carry two gallons where one gallon of gasoline was sufficient, on account of the calorific value of the fuel, but the efficiency resulting may perhaps overcome to a very large extent the disadvantages of alcohol as a fuel. We may not be obliged to carry two gallons in place of one. The advantages that we may get from no carbon, no poisonous gases, almost no odor from the products of combustion, make alcohol a desirable fuel.

Years ago a number of experiments were made to find out why the

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fuel leaked past the rings into the crankcase. That was just at the beginning of the fuel troubles, say 1909, possibly 1910. The experiments in the laboratory with which I was connected at the time led us to believe that if the boiling point of the fuel or of a large proportion of the fuel was above 300 deg. fahr., then about the only solution for the problem was to have rings through which it could not leak past, because the temperature of the piston itself at the walls of the cylinder seldom exceeded 350 to 400 deg. If the fuel had to be carried into the cylinders as fast as it usually is the heat generated in compression would not be sufficient in the time available to cause the evaporation of all of the fuel. A great portion of it must lie in the cylinder, on top of the piston next the walls, and this portion would naturally leak past the rings. I believe that unless we heat the fuel to a point where the volumetric efficiency of the engine will be somewhat reduced we cannot use the fuels that we have at the highest efficiency and prevent leakage past the rings. But as an offset to this result of heating we have the advantage, of course, of a more complete use and a higher efficiency of the fuel itself.

CHAIRMAN F. E. PLACE:—It appears that alcohol is a fuel that must be considered. What mechanical changes were necessary in the tractor engines to make them suitable for using alcohol?

FRED C. GLOVER:—Very few changes were necessary. We had to substitute a metal float, as we found the alcohol ate the shellac off the cork float; after that we had no trouble with the carbureter. We used the ordinary gasoline carbureters, two different makes, and each worked equally well. We were obliged to raise the compression from 95 to 115 lb. per sq. in. I think we used 1.05 lb. of fuel per brake horsepower per hour.

GEORGE W. SMITH:—There would not be any problem if the owners of automobiles would keep them at the right temperature. We have operated cars from cold and warm garages and find that if we can get them up to the proper temperature in a very short time, the accumulation of kerosene in the crankcase is comparatively small. It is not any hardship to require car owners to change their oil every thousand miles and either throw it away or distill the kerosene off.

The owner of a car does not want a laboratory job. If he did, we could give him something very nice. He has insisted upon maximum performance and never in the history of the automobile have we had the acceleration that we have at present, nor have we had the horsepower per cubic inch that we have now. In the face of a steady decline in the quality of fuel all this has been accomplished.

It is possible with given conditions to get good results for those conditions. If we want to operate in a cold climate, we can so hood the radiator and so fix the heating apparatus that proper results can be obtained. But it would be almost impossible to get the same apparatus to operate well in the tropics. It is almost impossible too to get the average car that is satisfactory in Pittsburgh to work well

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in Kalamazoo. I think that the chemists should be called upon to do a little bit of work determining specifications as to what should and should not be used as fuel in certain localities.

A great deal of work has been done by the automobile engineers, both in the laboratory and on the road, and we probably have gone just about as far as is possible with the present method of taking the fuel into the cylinder. Perhaps the next step is something in the way of the semi-Diesel engine.

We have had very little experience with alcohol fuel. We ran a test with alcohol as a fuel in the summer time and the engine developed about 90 per cent of the normal horsepower at 1000 rev. per min. with an economy of about 75 per cent on the road. I cannot see why it is not feasible to develop such a fuel if enough money and enough work is spent in research.

H. L. HORNING:—I am particularly interested in the statements of Doctor Burton, coming as they do from a man who is known among the petroleum technologists as perhaps the greatest authority today on the subject, and I wonder if we all appreciate the two messages that he has put into his discussion. The first message is that the fuel today is really not a bad fuel, and I want to concur with him in this opinion. The second is that in the near future it is not liable to be further decreased in quality. In other words, he implies that possibly for the next two years there will not be the continued rapid decrease in fuel quality that we have been experiencing the last two years.

A sphere is the ideal combustion chamber, for the reason that there is perfect cooling and a perfect temperature gradient between the surface on the inside and on the outside at the time of combustion. The necessities of engine construction have been met by the engineer with compromises. That chamber is the ideal chamber that will dissipate the greatest amount of heat without interfering with the combustion of the fuel. Inasmuch as something like 45 to 50 per cent of the heat of combustion is not dissipated to the water, it is becoming a severe problem to hold down the surface temperature of the combustion chamber.

In the ideal combustion chamber there must not be any part that loses its heat through a film of air, oil or any other substance. It must be continuous in order to conduct the heat perfectly. The ideal combustion chamber should have no screw threads because it then will not dissipate the heat perfectly. That is why the manufacturers of the valve-in-the-head engines tell us they have the ideal combustion chamber.

Fig. 5 shows cross-sections of two combustion chambers. The first compromise is the piston, represented by *1* in the figure. The connection between the piston and the cylinder is shown at *2*, where as we all know there is a gas film as well as an oil film. The exhaust and intake valves are shown at *3* and *4* respectively. The tapping of the spark-plug *5* is heated easily to a temperature so high as to give pre-

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ignition in heavy engines. The valve-chamber plugs are shown at *8*. The surface next the exhaust *9* is so close that it overheats that part

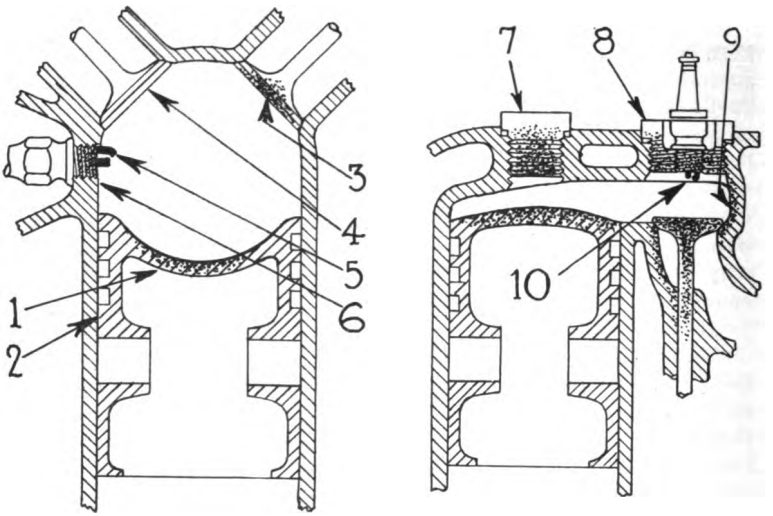

FIG. 5—CROSS-SECTIONS OF COMBUSTION CHAMBERS

of the cylinder. The point marked *10* indicates an arrangement with which the exhaust valves are heated unduly.

The ideal combustion chamber must be one in which there is a uniform temperature as high as possible in order to vaporize the fuel throughout the entire surface and a low maximum temperature as indicated by such spots as the middle of the piston, the middle of the exhaust valves and the spark-plug points. Concave piston walls have a tendency to break up the heavy constituents of the gasoline and make cooling very difficult. The spark-plugs and the exhaust valves constitute the important items that have to be considered in engines that are working to the limit, such as in tractors and airplanes. In the latter the heat is so intense and so continuous that the porcelain decomposes or changes in structure after a period of several hours. Studies have now been undertaken to improve the quality of the porcelain and correct the plug through improved design.

DR. H. C. DICKINSON:—We have found out a great many things about the behavior of porcelains when they reach the higher temperatures and have started out to devise a type of test that can be readily applied by makers or users of spark-plugs, but we have not completed this yet. Progress is good and we shall have something to report in the near future.

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PENNSYLVANNIA SECTION PAPERS

RETARDATION OF THE AUTOMOBILE

By John Younger

(Member of the Society)

During the past two or three years emphasis has been laid on the accelerative ability of cars. Designers have vied with each other in getting the last fractional inch per second per second into their performance curves. Advertising managers have not been slow in accelerating the peaks a little further and found that the public liked it.

Get Away, Pick Up, Dash, Verve—I myself have called it Elan—are all familiar terms for the engineer's word acceleration. There is as yet no such term of endearment for retardation. Its significance has not gripped the people's imagination, and yet of the two it is of more vital importance. The automobile death rate increases in inverse proportion to the efficiency of the retardation curve.

In fast rail traffic, with many stops, the possible retardation curve is first studied. A continual stream of cars passes through the New York Subway, with an extremely small headway at rush hours; as a result the motormen know almost to a fraction of a foot just where the brakes must be applied to stop at the required point at a station. In street car work the profit that can be derived from a set of rails in a busy district is as much a question of retardation as of acceleration.

TYPES OF RETARDATION

The automobile moving rapidly in and out of city traffic places, perforce, great dependence on its brakes. Good braking contributes greatly to the feeling of liveliness. A car with good acceleration, but sluggish retardation, does not feel as lively as one in which both are good. Retardation can be studied under two heads:

1—Retardation relative to the road.

2—Retardation relative to the forces acting on the car.

The primary object of (1) is to slow down and actually stop the car. The object of (2) is to maintain the vehicle at a steady and safe speed, notwithstanding the forces, such as effect of gravity on a hill, that tend to accelerate the vehicle.

The coefficient of adhesion or friction of the tire varies greatly with its shape, the nature of its tread, whether it be solid or pneumatic, and with the compound of rubber used. The fact that the road surface ranges from cement or vitrified brick to greasy mud makes it impossible to give accurate figures for the coefficient.

The coefficient of maximum adhesion for solid rubber tires on good

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macadam has been given* as 0.4 by George W. Watson. Other authorities state that 0.6 is correct for pneumatic tires. The author has found that the coefficient is 0.6 for solid rubber tires on cement and vitrified brick roads, and only 0.5 under similar conditions for pneumatics. The measurement of tire adhesion is, however, inextricably mixed up with that of road resistance, the number of factors entering in being exceedingly large. A convenient and accurate value to assume is 0.5, and this is concurred in by several authorities.

I have been careful to use the term adhesion as specially applicable to the case where the tire does not slip relatively to the road. When the tire slips the proper term is friction. There being no relative motion between the surface of the tire and the road (the road moving back at the same speed as the tangential velocity of the car), the case is analogous to a body at rest on an inclined plane. The coefficient of "stiction" or adhesion is greater than that of friction. Incidentally, this partly explains why a car stops more rapidly when the wheels are kept moving than when they are locked.

Smooth asphalt, concrete, brick, good macadam, which offer little resistance to the passage of the car, have fortunately a good coefficient of adhesion when dry, thus offering fair compensation. Road resistances vary from 5 to over 300 lb. per ton and must be considered in the study of retardation.

The wind resistance can be taken as $0.002\ Av^2$ in pounds where A is projected frontal area in square feet, usually about 25 sq. ft. This resistance varies with wind velocity and direction. Strictly speaking, it should always be considered, but its effect is small and can be neglected.

VALUE OF RETARDING FORCE

Given brakes on all wheels, and neglecting road resistances, the retarding force is 0.5 W. By substituting in the inertia formula $F = Wa/g$, we find the retardation is 0.5 g, or 16.1 ft. per sec. per sec.

The average automobile is fitted with brakes on the rear wheels only, and its weight is distributed equally on front and rear wheels.

The conditions are shown in Table I.

TABLE I—RETARDATION FACTORS AT VARIOUS SPEEDS

Car Speed, M.p.h.	Stopping Time, Sec.	Stopping Distance, Ft.
60	11	484
30	5½	121
15	2¾	30¼
5	⅝	4½

The presence of road and wind resistances and of chassis losses will increase the retardation from 8 ft. to almost 10 ft. per sec. per sec., so that a car traveling at 30 m.p.h. will stop in 4.4 sec. in about 97 ft.

*See Proceedings Institution of Automobile Engineers, 1915-1916, p. 162.

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Everyone has experienced the peculiar feeling of being shot forward in the seat when brakes are suddenly and strongly applied in a railroad train or a street car. The eyes have not prepared the body to brace against the action, whereas in an automobile the eyes are usually on the alert and the body is well prepared for violent retardation.

Yet, in railroad service the best stopping time is that recorded in March, 1914, when a Pennsylvania train, moving at 60 m.p.h., was stopped in 1000 ft. This took 22¾ sec., the retardation being only 3.87 ft. per sec. per sec. The train was equipped with an experimental type of Westinghouse brake.

An acceleration or retardation of 6 ft. per sec. per sec. is about all that can be borne in comfort by passengers. Extreme change, such as stoppage against a stone wall, will catapult passengers out of their seats with great violence. A retardation of 6 ft. per sec. per sec. is on the verge of discomfort; it is, I think, reasonable to believe that 10 ft. per sec. per sec. is the maximum. This, by the way, is equivalent to an applied horizontal pressure on the passenger of about one-third his weight. So with the chassis. The inertia effects on the body fastenings, engine and transmission fastenings are usually based on the low-speed acceleration, which is rarely more than 10 ft. per sec. per sec., the equivalent of a 30 per cent grade.

FOUR-WHEEL BRAKES

It is thus seen that for the average vehicle little is to be gained in putting brakes on more than the two rear wheels, even though four-wheel brakes might be adjusted to reduce the friction on each brake so that it is only half of what it might be with the two-wheel brakes. The four-wheel brakes are exceedingly difficult to keep in adjustment, and there is real danger in excessive retardation being produced under the normal circumstances of driving over dry roads. Railroad conditions are not analogous, as a coefficient of adhesion of 0.2 is about all that can be reckoned on, as against one of from 0.5 to 0.6 on rubber-tired automobiles.

Two-wheel brakes, provided they function properly and are used intelligently, will give all the retardation that it is safe to use. There are, of course, other reasons why four-wheel brakes have not been adopted generally.

The foregoing remarks have dealt mostly with a car whose weight is distributed equally fore and aft. The passenger load is usually a small percentage of the gross weight, and there is an obvious limit to the capacity of the space that can be used for carrying people. In motor trucks the weight of the load is often equal to that of the vehicle itself. Twice the rated load is occasionally carried, although this evil is, I think, becoming less prevalent.

In some trucks the load is about equally distributed between front and rear wheels. Usually 75 per cent and upward of the load is car-

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ried on the rear axle. The weight of a truck is not proportional to its load. A 2-ton truck with body may weigh 6000 lb.; its weight is one and one-half times that of its load. A 5-ton truck with body may weigh 10,000 lb.; its weight is then equal to that of the load.

Each truck must therefore be considered individually, and the braking effort on the circumference of the rear wheels be made equal to at least 0.5 times the loaded weight on the rear wheels. If the speed of the truck is 15 m.p.h., it can be stopped in about 30 ft. without causing the load to pile up behind the driver's seat. This distance should satisfy any law-making body, and should make it unnecessary to provide safety guards or fenders.

The effect of the human element in producing retardation is great. Brakes must be skillfully applied, so that under varying road conditions the pressure is just enough to not lock the wheels, otherwise a dangerous skid may result. Women in increasing numbers are driving cars. They cannot exert the pressure on a pedal or lever that a man can. Designers must awaken to this problem. If a light pressure is given, brakes must be adjusted more often, unless some mechanical or electrical means be supplied for assisting the driver. Such means must be delicately arranged so as to give perfect gradation of pressure, but the problem should not be impossible of solution.

ABSORPTION OF ENERGY

The question of absorption of energy has been ignored in the foregoing, inasmuch as the time interval is short, and the material surrounding the brakes capable of taking up the heat developed. On a long hill, when brakes are applied continuously, the problems that arise are different. Here there is no question of inertia effects, or of skidding, or of stopping space; the great question is one of absorption of energy and hence of radiation of heat.

At the top of a hill a car possesses both kinetic and potential energy. If at the bottom the car's speed is unchanged, then the brakes, plus the road resistance, have absorbed the potential energy. The weight of the car plays an enormous part in this, the absorption of energy being in direct proportion to it. While the truck lacks the speed of the touring car, its greater weight makes the retardation problem more difficult, particularly in hill descents.

Many hills have a 10-per cent grade and are ½ mile long. A 5-ton truck, gross weight 20,000 lb., has a gravitational component downward of about 2000 lb. Assuming a road resistance of 50 lb. per ton (of 2000 lb.), or 500 lb. gross, the net force tending to accelerate the truck down hill is 1500 lb.

If a safe speed of 10 m.p.h. is maintained the time of descent is 3 min. The energy absorbed by the brakes is 1500 $\times$ 2640, or at the rate of 1,320,000 ft. lb. per min. This is equivalent to 40 hp., or to 1700 B.t.u. per min.

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Since metal weighing about 50 lb., with a specific heat of 0.12, absorbs this energy, the heat generated in 3 min. (neglecting radiation) is sufficient to raise the temperature of the mass from 60 to 900 deg. F. The temperature required to dissipate the energy absorbed by the brakes was calculated to be about 760 deg. F.

We made an actual test with 1 sq. ft. of brake-radiating surface. The 5-ton truck mentioned was driven down the 10-per cent grade ½ mile long at 10 m.p.h. At the foot of the hill the temperature was certainly nearly 760 deg. F., the radiating surface being at a black heat.

There are hills much worse than this in length and grade; the only salvation then is the use of the engine, alternating with hand and foot brake. The normal brake is satisfactory for the greater part of automobile touring, but for hilly and mountainous districts there is still much to be done in improving brakes. European designers have been well aware of this; some of the Italian designers whose testing grounds are the Swiss Alps have even gone the length of water-cooling their brakes, both by drip and by water-jacket.

In only one truck, and that of Swiss design, has an attempt been made to solve this problem. A device is used that shifts the camshaft longitudinally, converting the engine into what is really a two-cycle air compressor, the carbureter being shut off and fresh air admitted through a manifold port.

From time to time brakes working on a hydraulic principle have been devised, but always there has been the problem of cooling the liquid and insuring the tightness of pipes and joints.

It is the author's belief that as country roads are opened up more, and motor trucks used in outlying districts, a demand will arise for a third brake for hilly districts. The vehicle can then coast down a long incline at a predetermined safe speed, with no wear and tear on the engine or undue heating of the brakes.

DISCUSSION

A. LUDLOW CLAYDEN:—I have felt for a good many years that we would not be satisfied with man-applied brakes. Carrying so much potential energy about with us in an automobile, why not make it do all the work? Driving in hilly country becomes tiring in the average car. I think that not more than three British cars will stand Alpine touring work. Of course, England is much flatter than the Alps, although it is much more hilly than the United States. The Italian and some of the French makers are the only ones making brakes adapted for long hills. The great fault of the Italian brakes is noise. Most of them are of course lined with metal rather than fabric. I use the word "fabric" to cover all kinds of woven brake material. Fabric linings are comparatively little used on the other side of the water. Cast iron is the favorite braking material but is

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almost impossible to make perfectly quiet in action. Unless it receives a great deal of attention, I do not believe that a metal brake can be used with any great success in a country where the normal road conditions are such that the wheels are likely to be kept smothered with water.

There is another point—that of taking the heat away from the brake. If we use a fabric lining, the conditions are more difficult than if we use a metal braking surface, because of the poor conductivity of the fabric linings, which means really that only the brake drum is left to carry away the heat. As a result the efficiency of the shoes must be considerably reduced. Phosphor bronze has been used, but, according to the general experience, it was too unreliable a material. It was not liable to rust, but it was prone to pick up and tear, just as copper will. The Sheffield Simplex Company of England has spent a great deal of time investigating brakes and made a successful expanding shoe brake as follows: The shoe was about 2 in. wide and was lined with strips about 2½ in. long, alternately of cast-iron and some other material. Cast-iron was tried with aluminum, with white metal, with phosphor bronze, and heavily compressed fabric. The last time I saw the people working on this brake—some two and one-half years ago—they said that the fabric and iron seemed to wear down evenly, the material in the fabric appeared to squeeze out and had a lubricating effect on the cast iron.

OPERATION OF SPECIAL TYPES

I have tried the electric brake, which has been on the market a long time. This brake takes a little training to handle it, but one can get an extremely delicate control as soon as he is accustomed to it. I hope soon to try the vacuum brake of the Prest-O-Lite Company. As far as one can judge on paper, its effect depends entirely on the delicacy of operation of the compensating valve. With such a device it seems quite possible to provide an adjustment so that the sensitiveness could be made to suit the driver. A powerful spring could be arranged to require about the same pressure as the accelerator pedal. If such a spring were placed somewhere beneath the plunger so that the driver would have to press one of his feet down hard, there should be no trouble. I do not see why an adjustable resistance should not be used. Of course, after a time it would not be needed, but in new devices it is often necessary to add features that can afterward be omitted.

ACTING CHAIRMAN B. B. BACHMAN:—We have been doing some experimenting with brakes. In order to facilitate the work the brake was mounted at the rear of the transmission, thus in some ways accentuating certain features of its construction. The speeds are much higher and the temperature conditions more severe.

The point that Mr. Clayden mentioned, as to the conductivity of the so-called fabric linings, is one that was forcefully brought to our

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attention. Our first construction was a pressed-steel drum, about ¼ in. thick. The brake was about 7 in. diameter. The shoe was lined with fabric. We found that in descending a normal hill the temperatures would rise to such an extent that the brake would not hold by the time we reached the foot of the hill; after a short amount of work with that brake the temperatures had increased to such an extent that we had an hour-glass effect in the drum. Following that we made a brake drum of steel and with it tried cast-iron shoes. On the whole the experiments gave us a better idea of the operating problems, and a graphic idea of the energy that has to be absorbed in controlling a vehicle. In our case we were handling a vehicle with a gross weight of about 10,000 lb.

Mr. Younger mentioned the laws being passed by legislative bodies. A serious and grave problem is confronting the manufacturers of commercial and pleasure vehicles because of the number of fatalities that have occurred. The legislation that has been passed does seem to be a serious effort to eliminate the trouble. They have simply tried to use patent medicines to cure a real disease. We want to determine the fundamental features of the disease and then apply cures for them.

W. M. NEWKIRK:—I have ridden in a car made by a Chicago company, in which the generator effect of the starting motor is used for the braking. This seems to give the maximum braking effect up to the point when the wheels begin to slip and momentarily stop.

LEON CAMMEN:—I have recently made some experiments on braking devices. As Mr. Younger stated, the brake has two functions: to stop the car on the level road and to hold down its speed on grades. The two functions are entirely different. We cannot possibly design a friction brake to do both things without giving it extreme dimensions. I tried to figure out the same problem that Mr. Younger has in his paper. I found that if a 3500-lb. car is going down a 12-per cent grade, at a reasonable speed of 10 m.p.h., with a properly designed unpainted brake the radiating surface must be about 800 sq. in.

The kind of paint on the drum makes a great difference in radiating properties—the characteristics of the paint and whether it is bright or dull. If the brake drum, the rear axle and some of the parts are painted, the radiating surface has to be probably about 900 sq. in. If a vehicle is descending a hill, say 1½ miles long, with an incline of 12 per cent, we will find that at the bottom the drum, the brake band and the fabric will be overheated. The fabric will be overheated to such an extent that the next time it is used and given a hard shove it will fall to pieces and the car will not stop.

I talked recently with one of the officials of the New York Police Department. He stated that in a number of accidents they have investigated the brakes and found to the great surprise of the driver, an

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experienced chauffeur in many cases, that they were entirely inefficient and incapable of stopping the car.

SOLUTIONS OF BRAKING PROBLEMS

There are only three solutions to this problem. One solution is to design the brake so large as to give it sufficient radiating surface. About seven or eight years ago I saw at the Benz factory a brake drum with little copper fins all over it. The object of the copper fins was of course to increase the radiating surface. Copper has not only a considerably higher conductivity than most metals, but, if properly treated, it will have a considerably greater radiation.

Now, curiously enough, ordinary copper—that is, smelted copper—will have a higher coefficient of radiation than electrolytic copper. Just why is not quite clear to me, although it is probably because electrolytic copper is considerably denser.

The size of the brake cannot be increased indefinitely, for the simple reason that if a surface of 800 sq. in. is required for a 3500-lb. car, one of something like 2000 sq. in. is needed to hold a 5-ton truck even on a moderate grade. We may finally reach the point where we cannot increase the radiating surface sufficiently to take care of the heat. There are other ways of handling the problem: One is to absorb the heat by means of some liquid which is cooled by fans. This method was tried in England and in Germany and proved entirely satisfactory. A second way is to absorb the heat by direct cooling. In doing this we encounter the difficulty Mr. Clayden mentioned, namely, the poor conductivity of the brake band.

I have made tests of the conductivity of some of the fabrics, and have found it is possible to increase the conductivity of the fabric by decreasing slightly its density. The conductivity of asbestos is extremely low. Air is a still better heat insulator, but it is queer that the heat conductivity of woven fabric is nearly inversely proportional to its density. In telephone insulation work it has been found that the denser the paper used for such purpose the worse electrical insulator it is; the best insulator is not the paper at all, but the air in the interstices of the paper.

NEW BRAKING SYSTEM

Another solution of the braking problem is to provide a system of taking up the down-grade acceleration entirely different from the friction brake. The principle of one such system can be described as follows:

Imagine that in some way the piston rod of an oil-pump, Fig. 1, is connected to the car wheel directly through the brake drum. Imagine also that the whole thing is immersed in an oil vessel. Then as the wheel revolves it will have to drive the oil from the pump into the oil vessel. Here all the work would be consumed over and over again in pumping the oil. In such a case all that would be necessary

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is to move the little valve in such a way as to modify the cross-section of the orifice.

This design involves a question as to what is the power the brakes must exert. I calculated that in order to stop a car traveling 50

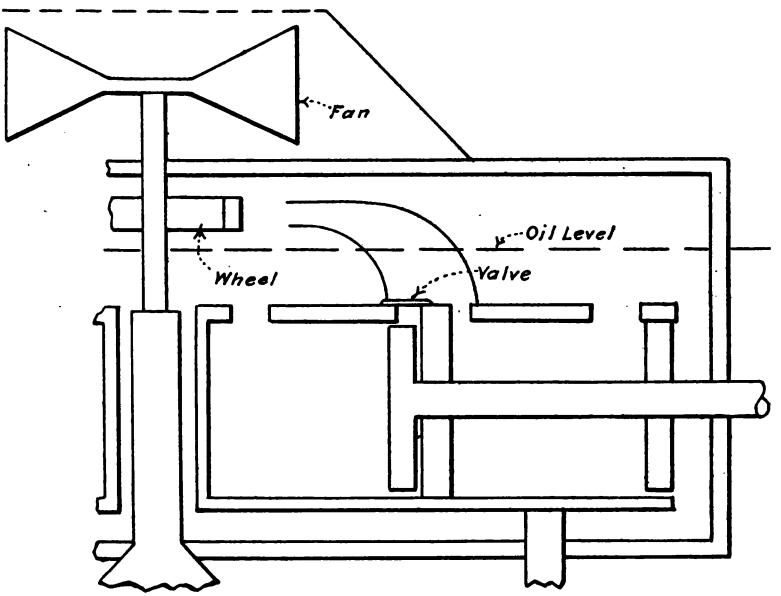

FIG. 1—ILLUSTRATING PRINCIPLE OF PROPOSED BRAKING SYSTEM

m.p.h. within about 350 ft. an effort on the brake equivalent to 450 hp. is required. If the brake were acting as a clutch the clutch would have to be between thirty and forty times larger than the clutch by means of which the engine drives the car itself. Of course no such effort could be taken care of on such a car. It is possible however—and in fact is practically done now—to design a brake so that the braking is effected in three stages. The first would be the closing of the clutch driving the pump; the second the gradual closing of the discharge orifice of the pump until enough is left to relieve the pump from excessive stresses; and the third the action of the usual friction brake.

The problem in all braking devices of the class described is that of consuming the heat. We do it by pumping the oil, but then what are we going to do with the heat developed in the oil while we are pumping it? The oil will heat to the very amount to which power is consumed by the pump. This has been solved as follows: The pump discharges the oil into a pipe, from which it flows on to a little wheel

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that has blades all around it. This wheel drives a fan on the outside of the casing. The oil is discharged in a stream. With a car weighing 3500 lb., going down grade at 10 m.p.h. it is discharging a stream at about 2300 ft. per min. This transmits to the little wheel about 6 hp., which is consumed in producing a powerful blast.

E. R. WHITNEY:—At one time I thought that truck brakes were not powerful enough, so I started to make one that would work easily; we arranged a device that would wind up in either direction, with the car going backward or forward. This brake was put on a 2-ton brewery truck. With the usual type of driver the block tires with which this truck was equipped were ripped out by the roots. On wet ground the truck would turn circles. So we had to go back to the old type of brake with which the drivers really had to do some pushing to apply it. That is important on truck work. The driver must be made to exert himself to apply the brake if any regard is given the tires.

The proper basis on which to design brakes is not how quickly the car can be stopped with everything right and on dry ground, but under the worst conditions—the truck going down hill, and with a wet pavement and smooth tires. Start on that basis and make the brake difficult to apply—so that it requires considerable effort. On dry ground it will be impossible to throw off the passengers. This idea will lead to four-wheel brakes and to uniform weight distribution, whether loaded or light. The four-wheel brakes have many elements of virtue.

We made some experiments at one time with front-wheel brakes. The car-load was distributed equally between front and rear wheels, and the front and rear brakes could be applied independently or together. We have found that front brakes are really safer than rear brakes and can be applied with less tendency to skid. If the front wheels were locked on wet ground the wheels turned for a considerable angle. At the same time, instead of skidding and the rear getting ahead of the front, it will push ahead in the direction the truck is moving, so that if with four-wheel brakes the brakes on the front wheels were stronger than those on the rear, a car could be stopped on wet ground much more quickly than with the rear brakes alone. The disadvantage, of course, is the complication and added cost.

DIAGONAL BRAKING

A. LUDLOW CLAYDEN:—The maximum directive power of a wheel is obtained only when it is rolling freely. As soon as the wheel is locked it is of no further directive value, no matter whether it is a front wheel or rear wheel; that fact led to the making of some experiments with a little wooden model, that could be rolled down a large table top, which was tilted. We found if the model was started down the slope with either the two front or the two rear wheels locked, it would take up all sorts of positions.

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By locking the wheels *a* and *d*, and leaving *b* and *c* free, Fig. 2, we obtained the best effect. Some time after this experiment was made the Argyll company produced a car in which the pairs of brakes were so linked. One set was operated by a pedal and the other by the hand lever; it worked out well. The only difficulty was the mechanical complication of making connections to the front wheels. Of course the cost of the front hubs with all their brake gear was considerable; the construction called for a number of universal-joints, levers and rockers.

Shortly after that the system was developed of applying friction brakes by a hydraulic device. A small pipe led down to the expanding

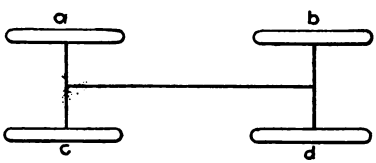

FIG. 2—VEHICLE FOR DIAGONAL BRAKING

cam, which was operated by a small piston, and pressure was applied on an oil reservoir. I think a car with that hydraulic brake had the most stopping power of any in which I have ever ridden.

AUTHOR'S CLOSURE

JOHN YOUNGER:—The diagonal brake mentioned by Mr. Clayden was tried in the London fire engines on the Dennis trucks, and it did produce a terrific retardation.

One reason why I have not studied the four-wheel brake seriously is that we are faced with the problem of maneuvering. We have to make trucks so that they can back up to yards, and it is important to be able to turn in a small circle. The mechanical difficulties are so numerous with a four-wheel brake that I have never attempted to solve them.

Mr. Whitney raised a point about the drivers of brewery trucks. These men usually weigh from 250 to 350 lb. We employed one of these men to do some testing. We asked him to push lightly, but he exerted an effort of about 450 lb. and broke the pedal. It is impossible to put a man like that on a truck and ask him to operate the thing gently. We expect a man to push pretty hard in order to stop his truck.

I think that the electro-magnetic or gasoline-electric car has not yet reached such a stage of development as has the ordinary gasoline car with straight mechanical drive; it is far too early to think that the magnetic principle of braking should be adopted. It is a beautiful brake, but at present we have to pay for it far too highly, on account of its cost and weight.

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The point that was raised about paints is exceedingly interesting, as was the point about the less dense fabric being a better conductor of heat than the dense fabric. That throws a great deal of light on an experience I have been unable to account for, namely, that the hydraulically-operated brakes, while standing up better than others for ordinary stoppage work have not stood up as well for long-haul work. I could never account for it. I thought that probably the breaking up of the fibers produced the disintegrated mass. Mr. Cammen's explanation is worthy of further investigation.

BRAKING MATERIALS

The whole problem of braking materials is a study in itself. I have tried many different materials and have come down to two at present; one is a good grade of cast iron and the other fabric; the fabric for short-stoppage and the cast iron for long-distance work.

If the ordinary brake drum is simply turned on its surface, little spikes will readily be seen on it upon examination under the microscope. If that surface is ground, the life will be a great deal longer. It is also important to see that the hardness is even; otherwise stresses will be introduced. It is advisable to keep sand away from the brake; some people dump sand on it as a kind of lubricant, and there is trouble.

Another thing that has been tried is the composite material—cast iron with plugs of bronze or copper. A 50-per cent mixture of lead and copper is an excellent braking material, but there is trouble when too much lead is used. That construction has been tried also with pieces of compressed brake lining squeezed into it, under pressure. A brake made in Philadelphia makes use of a material something like quartz. All kinds of brake materials have been tried out, but most of them have been designed to give longer life to the brake. Little has been done yet in the way of obtaining a greater radiating capacity.

The point has been raised about legal requirements. If I were a police commissioner I should like to enforce one law, and that is this: An inspector should be able to go on any car, provided the road is dry, and say of asphalt or good macadam, cement or brick, and make a brake test going at say 20 m.p.h. and within certain limits, and if the car does not stop, he should have as much right to take the driver into the police station as for breaking the speed limit. If that were done there would be fewer accidents. I think we should advocate it as leading to a prevention of some of the automobile accidents. The headway between automobiles is much less than it used to be, and people are so accustomed to them that they have become more careless. I think we ought to help the police authorities in their problem.

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POWER LOSSES IN PNEUMATIC TIRES

By E. H. Lockwood
(Non-Member)

An apparatus for power measurement at the rear tires of an automobile was installed in 1913 at the mechanical laboratory of the Sheffield Scientific School. A description of this apparatus, with an outline of a proposed method* of rear-wheel testing, was presented at the 1915 Annual Meeting of the Society.

During the summer of 1916 a calibrated motor was attached to the drums for the purpose of measuring the internal friction losses of tires and transmission system when driven by an external source. This addition to the apparatus led to a revision of the method of testing and the form of report, all aimed to give greater completeness and accuracy.

Considerable attention was paid to measurement of the internal friction losses, and many experiments were made on a six-cylinder chassis (this was a 6-30 Chalmers loaned by the Chalmers Motor Co.) of recent design. In connection with the work a series of tests was made on various elements that might affect car internal resistances, such as speed of car, inflation pressure in tires, load on the axle, and material or construction of the tires.

The information derived from these tests has proved so interesting that the principal results are now presented for discussion. The experiments have the limitation of being made on one size of tire only, and no claim is made that the entire question of tire resistance has been solved.

The method of obtaining the rolling resistance was to anchor the car with either pair of wheels on the center of the test drums, and then to rotate the latter by means of the calibrated motor. Two readings were needed, one with the car on the drums and one with the car removed, when the difference in power measured the rolling resistance of a pair of wheels. It has been found possible to avoid calibration errors in this operation by the use of the absorption dynamometer on the drum shaft, adding enough resistance by the latter so that all meter readings are duplicated when the wheels are removed. The dynamometer then measures the equivalent of the rolling resistance of the wheels. The available range of speed of the motor is from 40 to 20 m.p.h. at the circumference of the drums, and its maximum power is 15 hp. The diameter of the drums is such that 300 rev. are equal to one mile.

Extremely sensitive readings can be made in this way, enabling small variations in rolling resistance to be measured. One possible criticism of its accuracy is that the drum friction is increased when

*The Practical Testing of Motor Vehicles, A. B. Browne and E. H. Lockwood. S. A. E. Transactions, Part I, 1915, p. 68.

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the weight of the wheels is added to that of the drums. Careful measurement of the drum friction when running idle showed an effort of 4 lb. at the drum circumference at 20 m.p.h. and 6 lb. at 40 m.p.h. The drums weigh about 3000 lb.; the load on an average pair of wheels is about 1500 lb. It is certain the friction does not increase in proportion to the weight on the drum bearings, and the assumption that the drum friction is constant at different loads cannot involve much error.

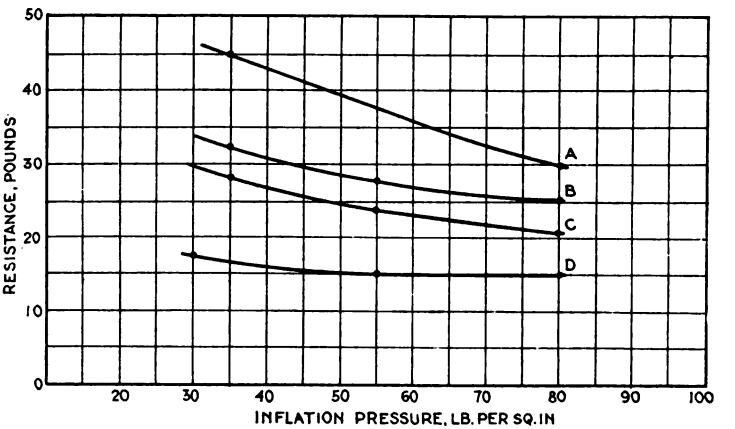

FIG. 1—ROLLING RESISTANCE MEASURED AT CIRCUMFERENCE OF 32 BY 4-IN. TIRES

A—Rear Wheels, Fabric Tires. Load 772 Lb. per Wheel.
B—Rear Wheels, Fabric Tires. Load 550 Lb. per Wheel.
C—Front Wheels, Fabric Tires. Load 570 Lb. per Wheel.
D—Front Wheels, Cord Tires. Load 570 Lb. per Wheel.

ROLLING RESISTANCE AT VARIOUS SPEEDS

One surprising result of all measurements of rolling resistance at speeds from 20 to 40 m.p.h. has been the slight increase of resistance at the higher speed. With some cars the increase of resistance is less than the observation errors. In other cases the increase amounts to from 5 to 10 per cent.

In reporting values of rolling resistance, the observations have been made at either three or four speeds covering the entire range, finally using the average of all the readings.

The results in Table I are given as an example of the amount of variation of resistance with speed. The readings are reported exactly as recorded. These cars differed considerably in rolling resistance, but in every case the speed of the car had little or no effect on the result. Rear-wheel tests were made confirming the results obtained with the front wheels; hence the conclusion from these tests that the internal rolling resistance of an automobile is practically constant at all speeds up to 40 m.p.h.

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DISTRIBUTION OF POWER LOSSES

The measurements described give as a result, the total rolling resistance of the front tire and bearings, or of the rear tires and all transmission losses up to neutral gear.

By an independent measurement the tire loss can be separated from the bearing and transmission loss. This is accomplished by jacking

TABLE I—ROLLING RESISTANCE OF FRONT WHEELS

Car No.	Tires	Inflation Pressure, Lb.	Load, Lb.	Speed, M.p.h.	Rolling Resistance, Lb.
1	32x4 Silvertown Cord	60	1120	20	11.7
				30	11.7
				40	13.8
				Aver.	12.4
2	32x4 Plain Fabric	55	1145	21	24.1
				27	25.0
				34	23.5
				41	24.4
				Aver.	24.25
3	35x5 Silvertown Cord	60	2100	21	33.0
				27	33.6
				34	34.2
				41	33.8
				Aver.	33.65

up the wheel until the contact between the surface of the tire and the drum is just sufficient to revolve the wheel. In this way tire resistance is practically eliminated, leaving only resistance due to bearings and transmission.

The internal power losses of the six-cylinder Chalmers chassis were determined in this way. The tires were 32 by 4-in.; load on front wheels, 1145 lb., load on rear 1545 lb.; tire inflation 75 lb.

The rolling resistance follows:

	Lb.	Per Cent
Front tires only	18.2	31.2
Rear tires only	17.7	30.3
Front bearings only	4.7	8.0
Rear bearings and transmission	17.9	30.5
Total	58.5	100.0

Dividing the four items mentioned into groups, we find that the tires alone are responsible for 61 per cent of the total resistance, while the axle bearings and transmission up to neutral consume only 39 per cent. The conclusion is that the tires are responsible for nearly two-thirds of the power lost in the car itself.

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The values cited are averages for speeds from 20 to 40 m.p.h., and as stated previously, the resistance changed little with the speed.

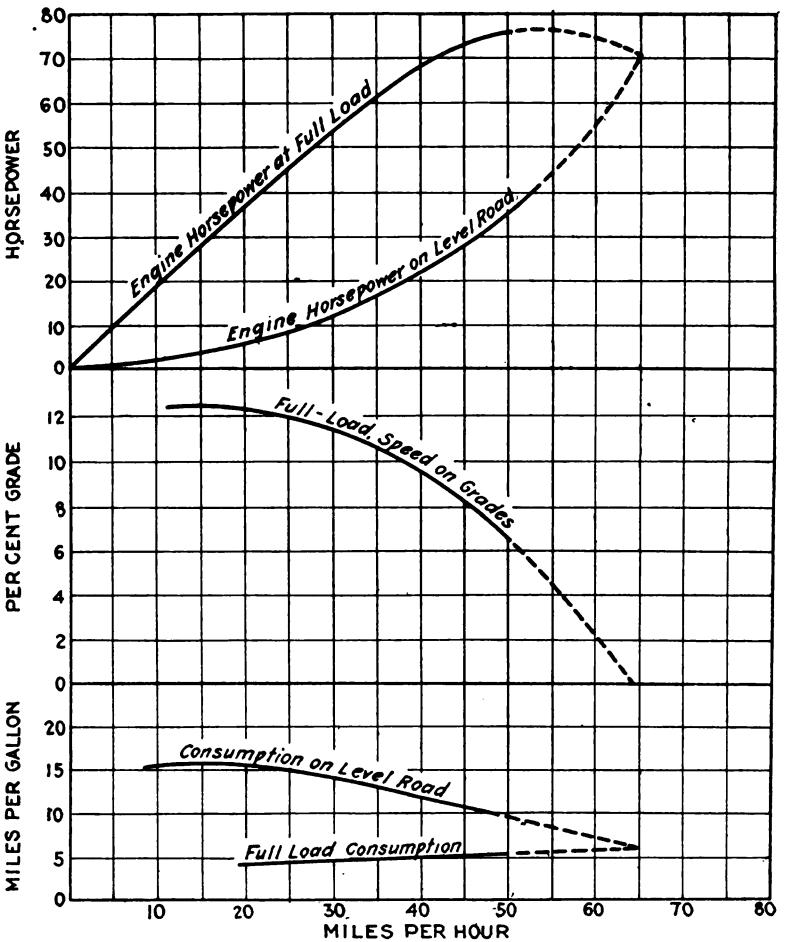

FIG. 2—PERFORMANCE CURVES FOR TWELVE-CYLINDER CAR

TIRE RESISTANCE AND PRODUCTION OF HEAT

The discovery that 61 per cent of the internal power loss of this car is expended in the tires, leads naturally to the question: What becomes of this power?

It is probable that friction of the material within the tire structure is continuously taking place, owing to flexure at the contact with the road. This absorption of work and production of heat is similar to the

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condition in a friction brake, except that the friction is produced by bending and not by sliding the fabric.

If these assumptions are true, it ought to be possible to calculate from the work absorbed the amount of heat generated; also to calculate the temperature of the tire surface when it reaches thermal equilibrium. The solution of this problem is worked out like that presented by a hot-water radiator, or, rather, as the wheel is revolving, by a hot blast heater.

These tires have 5.83 sq. ft. of surface, and the resistance at the circumference is 8.85 lb. At a speed of 30 m.p.h., 1810 B.t.u. per hour will be generated. In order to dissipate this heat in the air an increase of temperature of 39 deg. F. above that of the room will be required; this result is based on a heat transfer coefficient of 8 B.t.u. per deg. per hr.

This calculation was made in advance of any experiments, but was later verified by running one of the 32 by 4-in. tires for half an hour at 30 m.p.h., after which the car was stopped and the surface temperature taken with a mercurial thermometer. The room temperature was 70 deg. F. and the tire temperature was 107.5 deg., or a rise of 37.5 deg. as compared with the calculated rise of 39 deg.

This experiment confirms the theory that tire resistance is caused by flexure of the material, and leads logically to the conclusion that resistance will be increased by under-inflation and by over-loading.

INFLATION PRESSURE AND LOAD

Of the factors affecting rolling resistance, inflation pressure is perhaps the most important. A considerable change of resistance can be caused by a moderate change of pressure.

The load carried by the tire is also an important factor, and must be considered along with the inflation. It seems probable that for a given load there is a region of inflation below which the resistance increases rapidly.

This relationship can best be shown by a series of characteristic curves, in which rolling resistance is plotted against inflation for a number of loads. Fig. 1 shows an incomplete series of such characteristic curves for 32 by 4-in. tires.

The influence of inflation pressure is clearly shown in curve *A*, which represents the rolling resistance under normal load of rear wheels equipped with fabric tires. With reduction of inflation pressure from 80 to 30 lb. the rolling resistance increases from 30 to 45 lb.

When the load on the wheel was reduced the rolling resistance decreased from 30 to 25 lb. under high inflation pressure. Reduction of pressure caused an increase of resistance in this case but not quite so pronounced as in the first curve. Curve *B* shows the rear-wheel resistance under light load.

Curve *C* shows the resistance of the front wheels under load equal to that on the rear, and displays the same characteristics as curve *B*.

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The uniformly greater resistance of curve *B* is due to the transmission system being connected with the rear wheels.

An approximate calculation of the increase of power caused by under-inflation can be made from the above experiments. From Fig. 1, the total rolling resistance at 80-lb. pressure, front and rear wheels combined, is 51.9 lb., while the corresponding value at 30-lb. inflation is 72.5 lb. Adding to these values the wind resistance calculated for 25 m.p.h. (30 lb.) the total car resistance for the two cases is found to be 81.9 and 102.5 lb. The conclusion is that an increase of power amounting to 25 per cent can be caused by very much under-inflated tires.

CORD VERSUS FABRIC TIRES

Only a limited number of tests of cord tires have been made under conditions permitting accurate comparison with fabric tires.

One such comparison is shown by curve *D*, Fig. 1, where a cord tire, 32 by 4 in., was tested under exactly the same conditions on the front wheels for the whole range of pressures.

The characteristics of this cord tire are: Greatly reduced resistance loss and ability to run at low inflation without much increase of resistance.

While these experiments point to the value of cord tires for reducing tire losses, more numerous and exhaustive tests are required covering a wider scope.

Performance curves for a twelve-cylinder passenger car are shown in Fig. 2. Both front and rear tires were 35 by 5 in. The front tires were inflated to a pressure of 60 lb. and the rear to 65 lb.

DISCUSSION

A. K. Brumbaugh:—Have any attempts been made to measure the coefficient of friction with the wheels and drums running; or to determine the coefficient with either wheels or drums locked? It is the impression, backed by practical knowledge, that a tire holds to the road better if the wheels are kept turning.

Prof. E. H. Lockwood:—We have had a maximum pull at the circumference of the drums of 600 lb. and have never noticed any tendency to slip. We have never tried by means of low gear to make the tires slip on the drums, although this experiment has been suggested and may be carried out later.

The rubber in tires differs in quality, as shown by a fine rubber dust thrown off from the drums when making a power test. Some tires yield a quantity of this pulverized rubber which is found scattered on the floor; others show no signs of this although transmitting the same amount of power.

Slippage undoubtedly exists between the tire and the face of the

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drums, as shown in the tendency to grind off the rubber surface, but the amount of slippage is in my opinion very small.

SOURCE OF HEAT IN TIRES

A. K. BRUMBAUGH:—That slippage might be, in some measure, responsible for the heat which is assumed to be due to flexure, although the close check in the calculations is against this.

PROF. E. H. LOCKWOOD:—I think that most people would question my original statement about the source of heat. It was originally my impression that the heating of the tires was caused by the tendency to slip on the road. I feel sure now that it is caused almost wholly by the flexure of the material and is not due to any slippage. Just the same amount of heat was in evidence when we revolved the front tires as the rear ones. The tire manufacturer apparently has a problem on his hands, namely, to build up the cords and rubber in such a way that this injurious friction action will be absent. Nobody expects a spring to heat up; the valve springs, for instance, never do. But the rubber tires, being bent around, do heat up. I think it is quite possible to combine the rubber and the fabric in such a manner that they will act similarly to a steel spring—bend and come back without absorbing energy.

B. B. BACHMAN:—Professor Lockwood gives some figures showing the variation between the front-wheel bearing losses and what are termed rear-wheel losses, which I understand also include the losses in the transmission system. In this case did any resistance have to be overcome through the transmission, or was only the friction with the gears running idle measured, without any resistance whatever on them?

What prompts me to ask the question is some experimental work that Mr. Brumbaugh and I have conducted within the past year, using the Wimperis accelerometer. We have not had the time to really do any accurate research work, but have simply taken a few readings and tried to learn something from them.

We made a test on a car similar to the one used by Professor Lockwood. The retardation on this car with top and wind shield up, on a good tarvia road, running at 5 m.p.h., was 94.2 lb.; at 40 m.p.h. it was 198.7 lb. At 25 m.p.h., which Prof. Lockwood mentioned, it was 126 lb. Expressed in pounds per ton of car weight, the resistance varies from 55 lb. at 5 m.p.h. to 115 lb. at 40 m.p.h. Now a heavier car of the same year's make has a resistance of from 62.5 lb. to 120 lb. per ton. At 25 m.p.h. it is 86 lb. For the heavy car the total resistance is 148 lb. at 5 m.p.h. and 286 lb. at 40 m.p.h. The tire equipment on that car is, I think, 36 by 5 in. I do not know accurately what the tire inflations were on either one of those cars.

It seems to me illogical that the front-wheel bearings should take so much less power than those on the rear wheels; there are at least nine extra bearings and two pairs of gears included in the rear-wheel measurements that are not included in the front.

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FRICTION INDEPENDENT OF LOAD

PROF. E. H. LOCKWOOD:—The point raised by Mr. Bachman is an important one as it affects the entire question of friction lost in transmission. The question is, does the loss of power in friction increase with the load, or does it remain constant? Experiments with lubricated machines such as steam engines and gas engines seem to indicate a nearly constant friction loss, at a given speed, irrespective of load. I assume this same condition holds in the transmission system and bearings of a car, although this has not yet been confirmed by experiment. The same point arises in the use of our test drums, when the axle friction is measured with idle drums and the same loss is assumed to exist when the weight of a car is added. As before stated the resistance due to friction may increase slightly with the load, but there is good reason to believe that the increase is slight and may be neglected without appreciable error.

B. B. BACHMAN:—I can conceive that in case the journals and rotating parts are lubricated and have special ball or roller bearings, a variation of load would not affect the friction materially. My principal question is: What is the effect of gears in mesh? I do not know of any data on gear losses under variable loads. It would seem to me that they would vary considerably. In a transmission under load I do not know whether we can assume that the spur gears or bevel gears running under load are absolutely in rolling contact. I am inclined to believe there is some sliding there, and if there is sliding it may come under the same head as journal friction, or it may not.

PROF. E. H. LOCKWOOD:—I do not believe I have any data on the subject, but it offers an excellent suggestion, and somebody should investigate the matter.

OPERATING EFFICIENCY OF GEARS

B. B. BACHMAN:—Considerable data have been published on the efficiency of worm gears, but unfortunately, when the tests are analyzed, it is found that they have not been made under conditions met in operating a car, such as high torque values at low speeds. The results might apply running along the level, but when applied to conditions met in climbing a steep hill, or through sand, the data are woefully misleading.

B. D. GRAY:—I have taken the efficiency of bevel gears at from 80 to 85 per cent under normal operating conditions. I think that in this car tested by Professor Lockwood the efficiency of the bevel gears was 80 per cent. The results obtained by Professor Lockwood and Mr. Bachman, in the same car, are nearly alike if we figure that the loss in the gears is 20 per cent. Correcting Professor Lockwood's 102 lb. for the gear loss, we come pretty close to Mr. Bachman's value of 126 lb.

The abnormally high coefficient of friction in the front-wheel bear-

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ings is surprising, even though they are of roller type. I understand that the figures were obtained by driving the front wheels partly jacked off the drums, so that there was just enough friction between the tires and the drums to overcome the friction in the bearings themselves. I think this coefficient of friction is something like 5 per cent; in other words, the 75 lb. required to turn those bearings seems abnormally high.

PROF. E. H. LOCKWOOD:—The jacking up of the front wheel in this test probably was not well done. The front tire shows a half pound more pull than the rear tire; they ought to show the same. The resistance is probably too high for the front bearings, but I am sure the total for the car is right.

EFFECTS OF TIRE CONSTRUCTION

CHAIRMAN JOHN W. WATSON:—What part of the internal resistance is due to the suction of the tire on the road or drums; there must be some suction, and it would become greater as the tire becomes softer.

PROF. E. H. LOCKWOOD:—I do not know about that, although I have been interested in what the effects of the vacuum cups were.

A. K. BRUMBAUGH:—There must be some suction with plain treads, because they tear a road to pieces. It requires energy to suck the dust from a road and throw stones all over the neighborhood.

PROF. E. H. LOCKWOOD:—Our tire experiments were incidental to the general problem of making a complete power test of a car. This will explain why many important points were not investigated.

In beginning power measurements at the rear tires, it was discovered that the inflation pressure produced a noticeable effect on the fuel consumption of the engine. This led to making all tests at uniform inflation pressure, and finally to measurement of the difference in power loss due to various inflations, and loads.

It is hoped to follow up this beginning by repeating the experiments on other tires of various sizes, when some of the questions raised here may be answered. It is important, of course, to be sure that the methods are right, leading to correct results. The suggestions made in this discussion will be most helpful.

R. E. PLIMPTON:—I should like to ask Professor Lockwood if the electrical readings made during the tests were fairly constant.

PROF. E. H. LOCKWOOD:—We had practically constant voltage, but the ammeter needle would sway back and forth. We were in a building where there was an elevator, and we generally waited a minute to let the needle swing back and forth. We could not measure a single reading there closer than half a pound, I am sure; so that when we plot the results on cross-section paper the points are pretty well staggered, but we could repeat the tests and get corresponding results. When we repeated them on the Chalmers car six weeks apart, they did not agree exactly, their variation being as much as

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three pounds. During that time the car had been overhauled and the bearings changed, which ought not to affect the transmission but we did not check up to the pound on the rolling resistance of the car. I feel sure that that was due to the car and not our apparatus —a brake band or something like that—and that there was really more or less friction in the two cases.

R. E. PLIMPTON:—Professor Lockwood gives a temperature obtained from calculating the heat energy absorbed, which is within 2 deg. of that found by actual measurement. It seems to me that that is pretty close work, because his calculated value must necessarily be an average value. If he takes but one measurement of temperature, it must be done quickly with a thermometer to get a true reading before the tire cools. If three or four measurements were taken, the results would be more accurate, and the tests might be more nearly comparable.

INFLATION PRESSURE AND TEMPERATURE

PROF. E. H. LOCKWOOD:—If the heat is given out by the flexure of the rubber it goes more or less into the rim, the metal parts and the rubber casing. I assume that the rubber would be a better conductor of heat than the wood and that the heat would be all diffused. I presume that the rim would dissipate some of the heat too.

We measured the temperature by placing the thermometer bulb on the tire, protecting it by a piece of waste. The rubber was apparently of uniform temperature at the surface, and retained its heat for some time after running. The inflation pressure of the two tires differed by 6 lb., one being our standard pressure, and the other lower. The surface temperature of the two tires differed by one and one-half degrees, the one with lower inflation being hotter. This difference confirms the theory that the effect of lower inflation is greater production of heat.

I have reported this experiment as helping to explain the cause of tire resistance, and I believe the observations are substantially correct even if made with simple appliances.

A. K. BRUMBAUGH:—In order to get efficiency out of the tires, is it necessary to inflate them so hard that one cannot possibly stay in the car?

PROF. E. H. LOCKWOOD:—I should say that the best power efficiency is obtained by running the cars with the tires very hard; let the tires stay hard and get the comfort in some other way.

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METROPOLITAN SECTION PAPER

HEAD-LAMP DESIGN AND ITS EFFECT UPON GLARE REDUCTION

By Alden L. McMurtry

(Member of the Society)

The problems of the head-lamp have been discussed from practically every viewpoint without arriving at any decision on most of the points in question. The result has been to add to the confusion already surrounding the subject. Some of the numerous arguments put forth disclose a lack of experience either in the use of head-lamps or with the average conditions that obtain in night driving.

Types of Head-lamps. There are two distinct types of head-lamps in use to-day, namely, the acetylene lamp with its lens-mirror and acetylene flame as a source of illumination, and the electric lamp with its paraboloid reflector. But since only a small percentage of the total are acetylene lamps we shall deal only with the electric type.

Purpose of the Paper. It is the purpose of this paper to review the design and operation of the electric head-lamp in use on automobiles at the present time; to review the principles involved in glare reduction and to draw conclusions regarding the merits thereof.

As the subject dealing with the effect of glare is a study in itself it will not be considered in this paper. It should be noted however that any light of sufficient intensity to illuminate properly a road used by motor vehicles will, unless properly directed or modified, cause the effect of glare upon users of the road who are facing the light.

Terminology. The terminology used in referring to the component parts of the head-lamp is as shown in Fig. 1.

HEAD-LAMP PARTS AND THEIR FUNCTIONS

The essential units of a head-lamp from the lighting point of view are the reflector, bulb, and socket, (including the socket-adjusting device). The three are of equal importance in the design of a head-lamp.

Paraboloid Reflector. The reflector is a paraboloid mirror or reflecting paraboloid usually made of metal, the reflecting surface being of silver or nickel, or in some instances gold. An axial section of the reflector surface is a parabola.

Suppose the reflecting surface to be a true paraboloid and the source of light to be a mathematical point located exactly in the focus of the reflector. Then all light rays, which emanate from this

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point and which strike the reflecting surface, will be reflected in a direction away from the apex in lines parallel to the axis of the reflector. Fig. 2. An ideal reflector and point light-source would thus have a uniform parallel beam the sectional area of which would be equal only to that of the projected area of the reflector. This condition is not only impossible but undesirable for practical purposes. It is

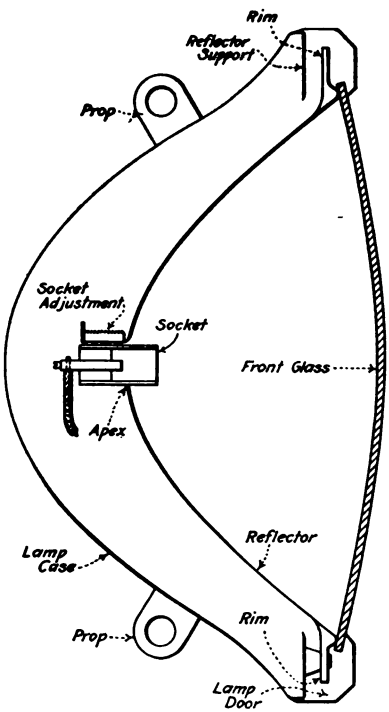

FIG. 1—SHOWING NAMES OF HEAD-LAMP PARTS

considered only to show the fundamental theory of the projection of light from a paraboloid surface.

If a paraboloid reflector is made within reasonable manufacturing tolerances it will more than fulfill all reflector requirements for automobile purposes for the reason that the source of illumination is not a point but an area of considerable magnitude.

Reflector Support. The support of the reflector within the lamp housing is an important matter if the direction of the cone of light emitted is to be restricted or confined to a certain area. The average reflector is supported by three or four hooks, which also hold the lamp door. Fig. 3.

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Holding the reflector to its support by a number of screws is the most logical method of securing a permanent position. Fig. 4.

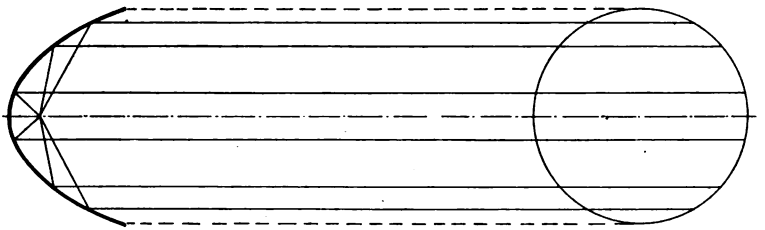

FIG. 2—RAYS OF LIGHT UNDER IDEAL CONDITIONS

Socket-Adjusting Devices. The socket-adjusting device, otherwise known as the focusing device, is the most important detail in the design of a head-lamp. It permits or should permit of a forward and backward movement of the socket along the reflector axis in order

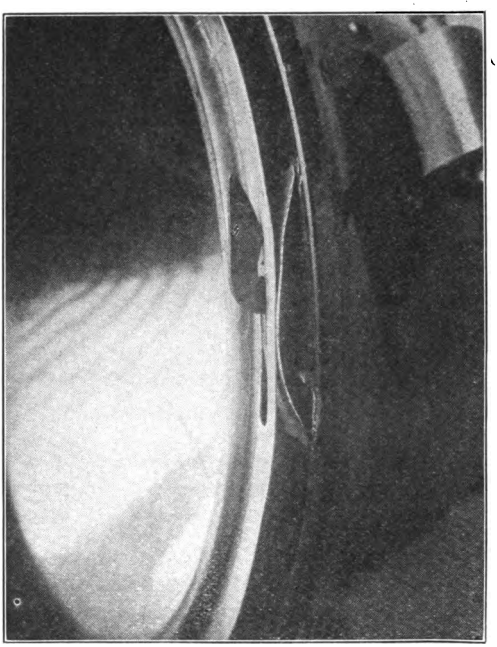

FIG. 3—HOOK METHOD OF SUPPORTING REFLECTOR

to place the source of light in proper relation to the reflector. Fig. 5. One of the almost universal defects of head-lamps is the limited socket adjustment. In some lamps the possible adjustment is about one half of what it should be, so that satisfactory results are obtainable only from a specific size and type of bulb.

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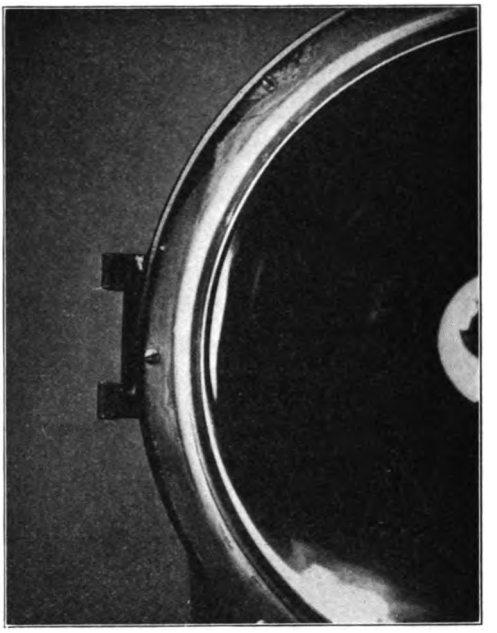

FIG. 4—REFLECTOR HELD IN POSITION BY SCREWS

A number of 1917 cars are fitted with head-lamps in which the socket adjustment is so limited that it is impossible to adjust properly the bulb with respect to the reflector.

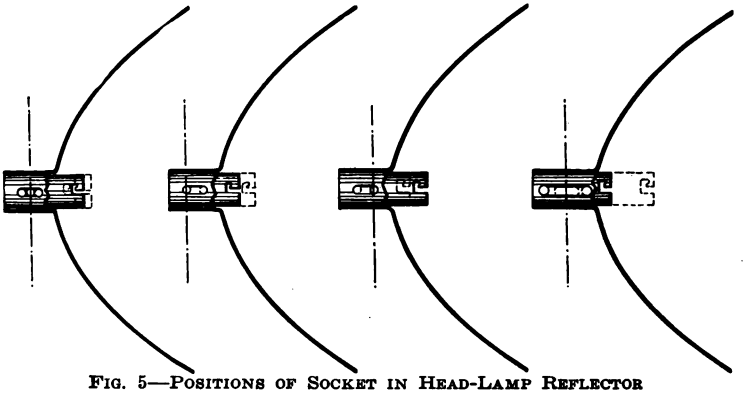

FIG. 5—POSITIONS OF SOCKET IN HEAD-LAMP REFLECTOR

Various types of socket-adjusting devices and methods are supposed to lock or maintain the socket in position. I shall classify them by the manner in which they are operated.

The *external adjusting* type includes all devices that permit of

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socket adjustment without opening the door or disturbing any other part of the lamp. Fig. 6.

The *rim-adjusting* type includes all devices that permit of socket adjustment at the rim of the reflector. Fig. 7.

The *bulb-adjusting* type includes all devices in which the adjustment is obtained by pushing, pulling or rotating the bulb. Fig. 8.

The *rear-adjusting* type includes all devices that operate from the rear of the reflector and require that the reflector be removed to make the adjustment. Fig. 9.

While the socket-adjusting device is the most important part of the lamp it is unfortunately most frequently defective. Lost motion in the socket-adjusting device not only makes it difficult to focus properly a bulb but permits the vibration of the car to alter its position.

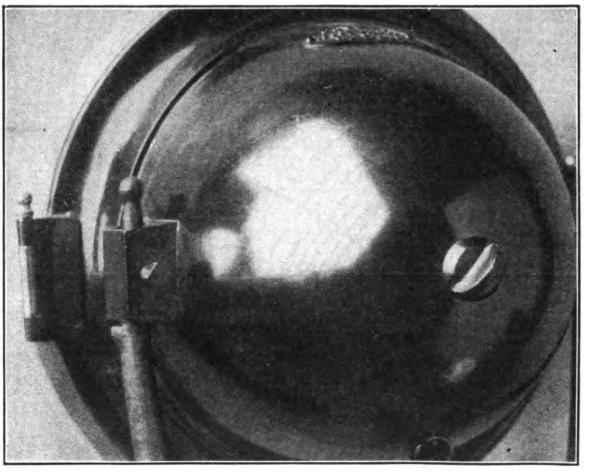

FIG. 6—EXTERNAL TYPE OF ADJUSTING SOCKET

The bulb-adjusting type is undesirable because if it is sufficiently stiff to retain the bulb in position, the latter tends to become loose from its base during adjustment. This is true particularly of those devices in which the adjustment is obtained by rotating the bulb. It is not unusual in the use of this type of device for the bulbs to break in the course of adjustment and cause injury to the hand in spite of the use of gloves.

Another defect of the socket-adjusting device that is not generally understood or appreciated is the lost motion in the device itself or between the socket and the bulb base. This lost motion permits displacement of the light source radially, that is, out of the reflector axis. Fig. 10. A small displacement of this character distorts the beam to a

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considerable extent and causes a distressing light distribution. The subject of radial displacement is of considerable importance and will again be considered under the heading of bulb bases. Any socket-adjusting devices that require or permit of radial displacement of the source of light should not be tolerated.

It is difficult to secure proper focusing and, in some cases, proper aiming, with any type of socket-adjusting device, unless it is readily accessible without partly dismantling the head-lamp. Such devices are therefore not to be recommended. It is difficult enough for the layman to secure correct adjustment without his having to dismantle (and perhaps incorrectly assemble) the head-lamp to do it.

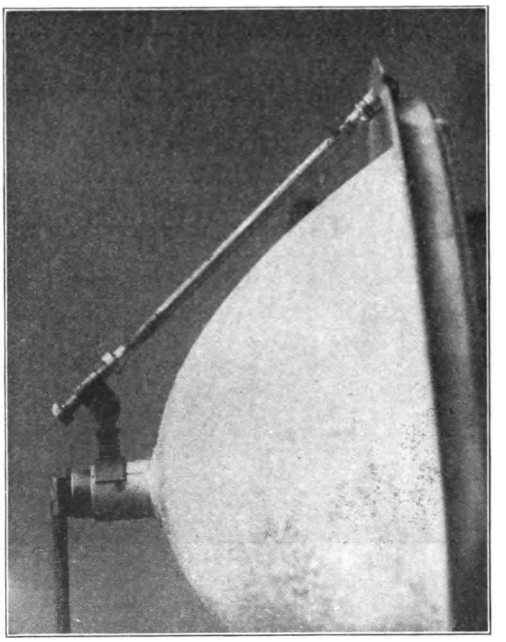

FIG. 7—RIM TYPE OF ADJUSTING SOCKET

Bulbs and Bulb Parts. The bulb is the complete unit containing the source of light. It consists of a globe, base, and bulb mount (including the filament). The different portions of the bulb will be referred to in the manner indicated in Fig. 11.

Types of Bulbs. The two general types of head-lamp bulbs are known commercially as the *B* and *C* types. The *B*, or vacuum type, contains a tungsten filament, generally in the form of a helix. The average axial length of the coil is about 15/64 in. and the maximum diameter 9/32 in. In the early types it was necessary to anchor the filament to protect it from vibration, but refinement in the methods of

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manufacture have increased the strength of the filament and have made the anchorage unnecessary.

The *C* type is a recent development, which produces more light for a given current consumption than does the *B* type. The *C* type bulbs are filled with an inert gas, one object being to allow the filament to attain a higher temperature without disintegration, which is one of the factors determining the life of a bulb.

Bulb Base. Prior to the introduction of the automobile head-lamp bulb all miniature bulbs were fitted with the miniature or candelabra-screw type of base. This type was soon discarded because the vibra-

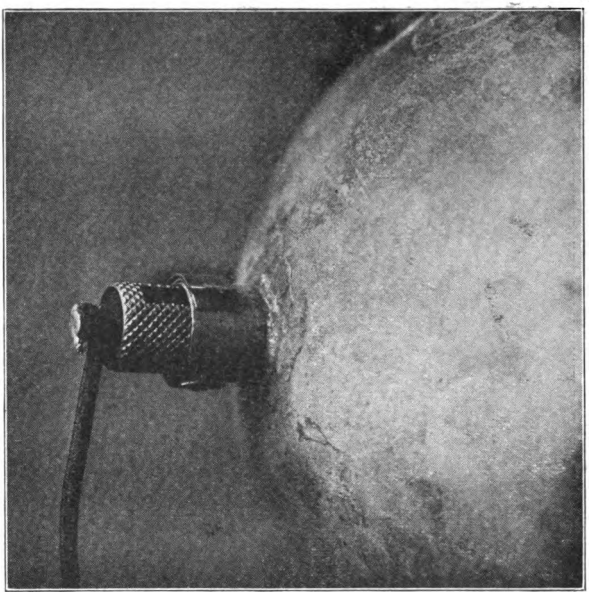

FIG. 8—BULB TYPE OF SOCKET ADJUSTMENT

tion loosened the bulb from the socket. The present bulb base, known as the Ediswan or bayonet type, has been adopted because it cannot be loosened by vibration and also because the position of the base in the socket is always the same. As standardized by the Society of Automobile Engineers there is a clearance of from .003 to .007 in. between the socket and the base.

Globe. The globe or glass envelope of a head-lamp bulb is generally spherical in form, the two sizes used for head-lamp purposes being respectively 2 1/16 and 1½ in. diameter. Other forms of globes have been made from time to time with different ideas in view. The advantages gained by the use of a tubular or straight-side bulb, aside from a question of stray light, are more imaginary than real.

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The shape and size of the globe are referred to by letter and number. For example *G* indicates a globular form and the number following it indicates the number of eighth-inches in the nominal diameter, thus: a G-12 globe is a round or globular envelope, 1½ or 12/8 in., diameter.

Filament Shape. No unit of a head-lamp has undergone such numerous changes from time to time as has the shape or form of the filament. A few of these different forms are shown in Fig. 12, including both the *B* and the *C* types.

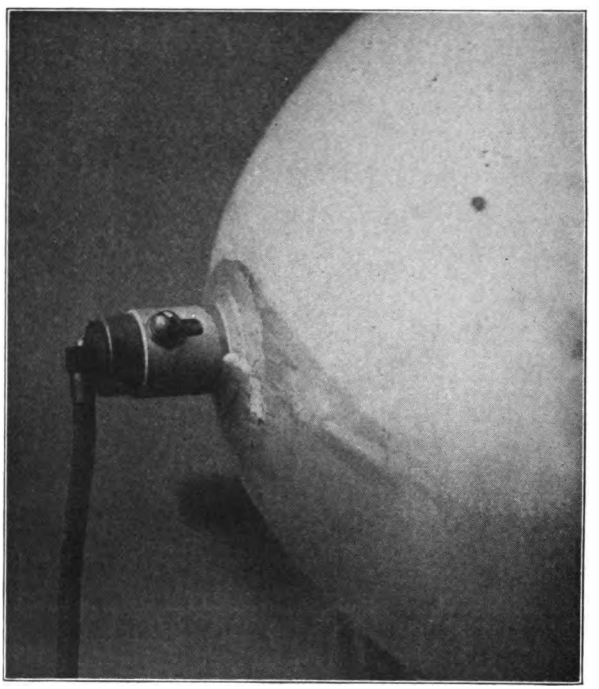

FIG. 9—SOCKET ADJUSTED FROM REAR OF REFLECTOR

The *filament area* is the area of the cross section through the axis of a solid figure formed by the rotation of the filament about the base axis. In the case of the so-called vacuum type helical-coil filament, the cylinder formed by the rotation of the filament has a cross section through its axis with a height and breadth equal to the length and diameter respectively of the helical coil, the product being termed the "filament area." In like manner the rotation of a gas-filled type of bulb with a V-shaped filament produces a cone whose cross section through its axis of revolution is a triangle.

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If this area of the filament is small the image produced by the bulb is correspondingly small. On the other hand if the area is exceedingly large the image will be large but of considerably less intensity.

The peculiar construction of the type *C* or gas-filled bulb filament

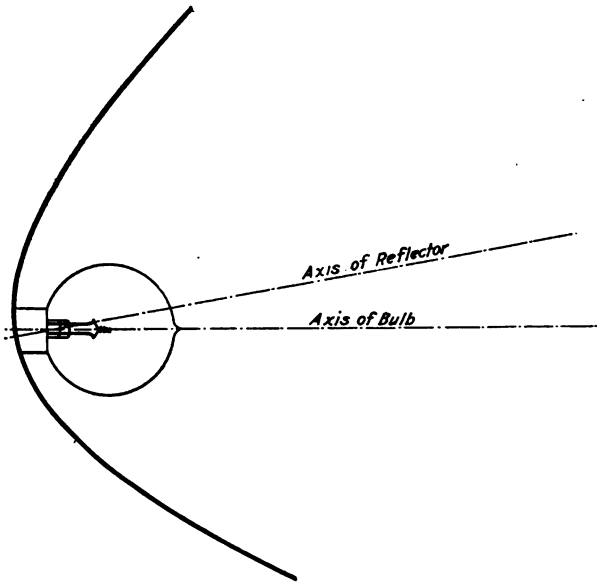

FIG. 10—POSITION OF BULB DUE TO LOST MOTION IN SOCKET

permitted the latter to be formed in various shapes. It is only within the past year that the bulb manufacturers have made any experiments

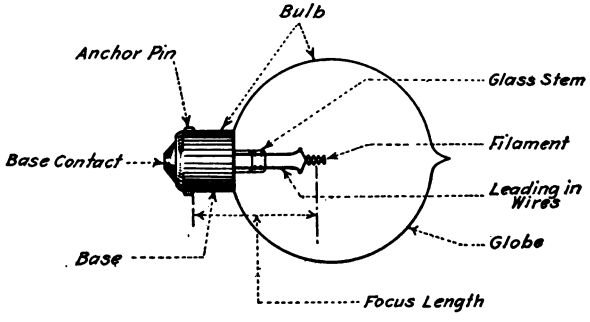

FIG. 11—TERMINOLOGY FOR PARTS OF BULB

to ascertain the resultant beam of light when bulbs of different filament-shapes were placed in an automobile head-lamp.

Focus Length. The focus length of a bulb is the distance from

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the center of the filament to the filament side of the anchor pins. Bulb manufacturers have been able to keep the focus length within close limits. One detail of bulb manufacture, the importance of which has only recently been realized, is the necessity of placing the center of the filament in the axis of the bulb base. With the *B* type of filament, which covers a large area, this item was not considered seriously, but with the small concentrated *C* type filament it becomes an important

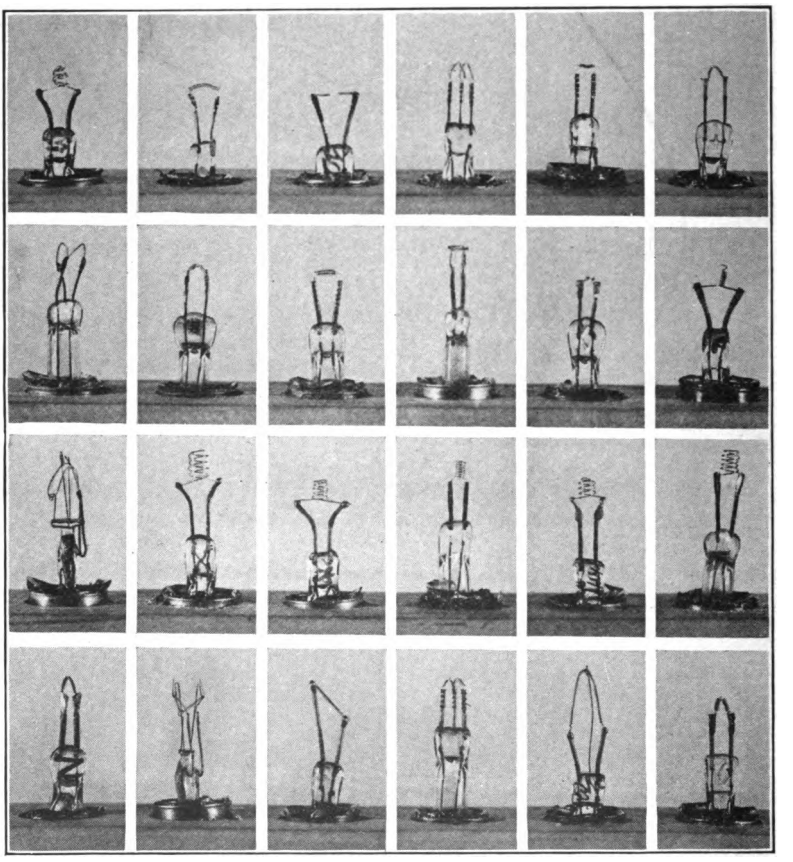

FIG 12—EXAMPLES OF HEAD-LAMP BULB FILAMENTS

factor in the attempt to get a uniform beam of reflected light from the head-lamp.

FOCUSING THE BULB IN THE HEAD-LAMP

We have considered the fundamental theory of the projection of light from a perfect paraboloid reflecting-surface and a point source of

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light. We shall now see what happens when the light source is not a point.

As the focus of the reflector is a point, it is evident that only one point of the filament of the bulb can occupy this position, and rays emanating from this point, after reflection, will proceed in lines parallel to the axis of the reflector. Rays from all other points of the filament, however, will be reflected from the reflecting surface at an angle to the axis. This is the reason why each point on the re-

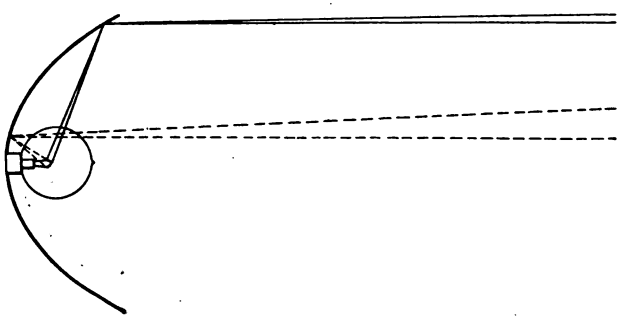

FIG 13—LIGHT CONES NEAR EDGE AND APEX OF REFLECTOR

flector reflects the image of the filament and sends out a cone of light. The cones emanating from points on the reflector near the apex have bases of considerable area while those reflected from points near the edges have small bases. Fig. 13. The resultant beam is a blending of these cones and the illumination produced depends entirely upon the form and area of the filament.

Having described separately the essential units of a head-lamp we shall note the various results obtained in the projection of light. The first important operation after placing the bulb in the socket is the

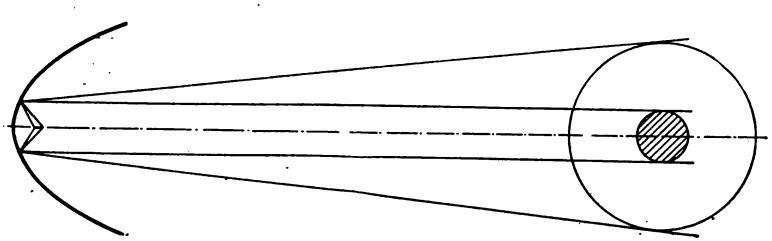

FIG. 14—IMPERFECT IMAGE—DIVERGING LIGHT RAYS

focal adjustment. This adjustment depends upon the form of the reflected cone of light desired. Previous articles describing the operation of focusing a head-lamp have contained no set of terms to designate the different results. As it is practically impossible for the

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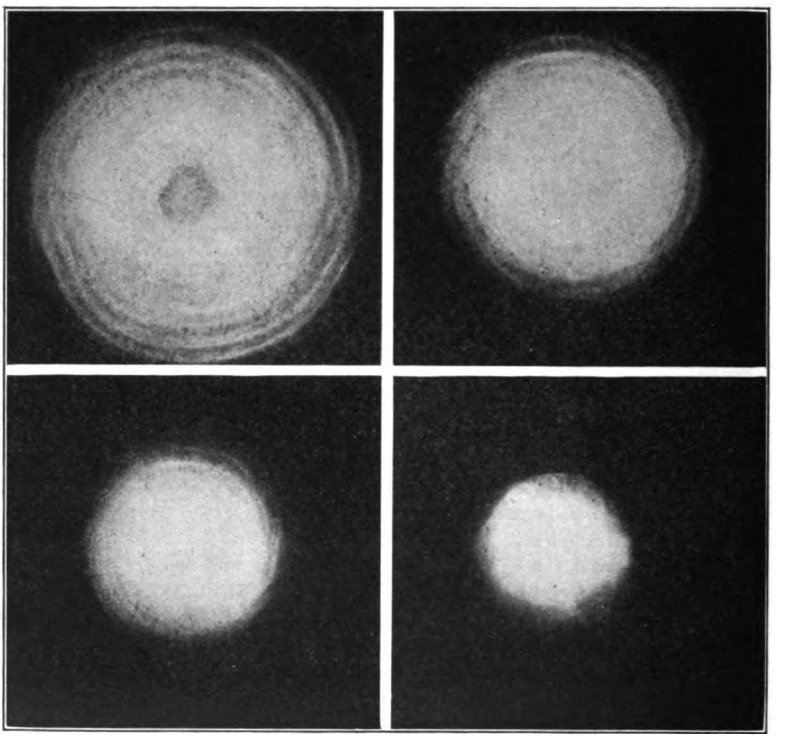
average person to determine the location of the center of the filament with respect to the focal point of the reflector any description based on such a point is indefinite. I have found it desirable therefore to refer to the focal position of the bulb by the image the reflected light makes on a screen, fence, or other plane surface perpendicular to the axis of the lamp at a distance of not less than 10 ft. Similar images



LIGHT IMAGES OBTAINED IN ADJUSTING BULB FOCAL POSITION—Fig. 15 (Upper Left), Imperfect Image—Diverging Rays. Fig. 17 (Upper Right), Large Image—Diverging Rays. Fig. 19 (Lower Left), Medium Image—Converging Rays. Fig. 21 (Lower Right), Small Image—Pencil Rays

can be obtained from the lamp in two ways, namely, by diverging rays, and by converging rays.

Starting with the filament of the lamp placed back of the focal point we have an image with a black spot in the center. Figs. 14 and 15. This adjustment is undesirable because the light distribution upon the road is such that black spots are visible. The majority of the rays in this case are useless because the wide angle of projection carries them to a considerable extent off to the sides and up into the

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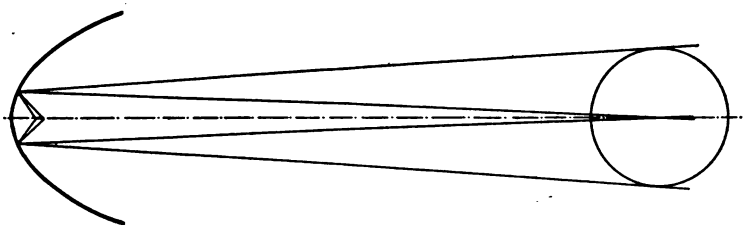

FIG. 16—LARGE IMAGE—DIVERGING RAYS

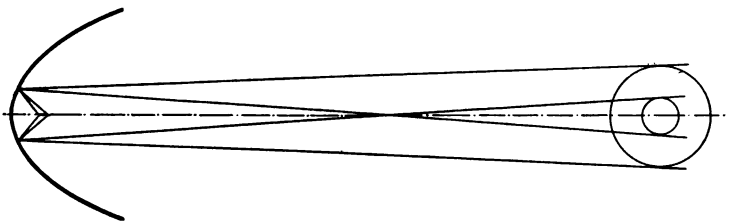

FIG 18—MEDIUM IMAGE—CONVERGING RAYS

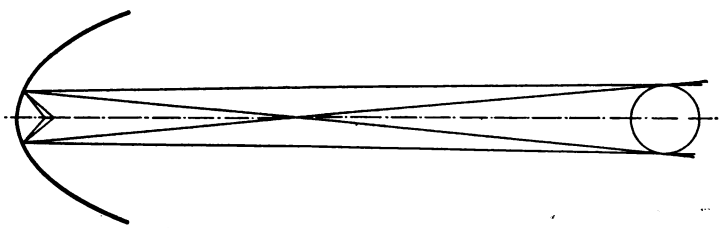

FIG. 20—SMALL IMAGE—PENCIL RAYS

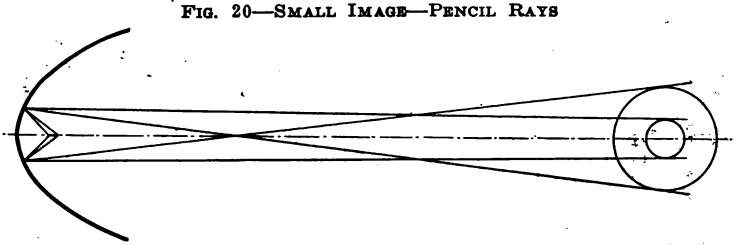

FIG. 23—MEDIUM IMAGE—DIVERGING RAYS

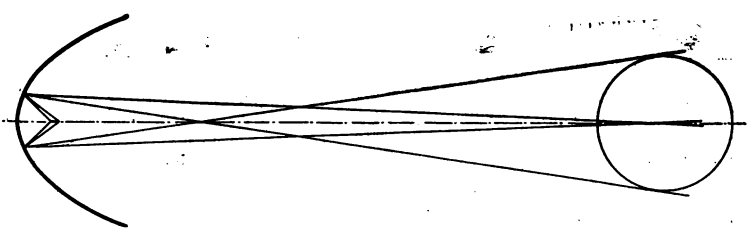

FIG. 24—LARGE IMAGE—CONVERGING RAYS

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air. This adjustment, which unfortunately is extensively but often unknowingly used, has helped to cause glare agitation.

The next adjustment is that in which the bulb of the lamp is moved slightly forward so that the black spot is eliminated. Figs. 16 and 17. This adjustment is known as the large image and gives the greatest angle of unbroken light. Again moving the bulb slightly forward we get an image, the diameter of which is considerably smaller, but as the cones of light projected from the reflector partly

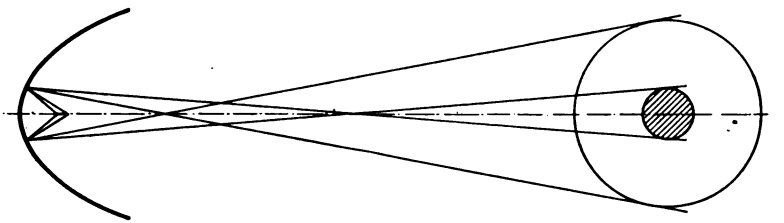

FIG. 25—IMPERFECT IMAGE—CONVERGING RAYS

overlap we get a second or smaller and concentric image, but one of greater brilliancy, Fig. 18 and 19. By moving the bulb forward until the center of its filament is slightly in front of the focal point of the reflector we find that the two images observed in the previous position now completely overlap and make one image of maximum intensity, Figs. 20, 21 and 22. This is the smallest image that can be obtained by a focal adjustment unless the area of the filament is

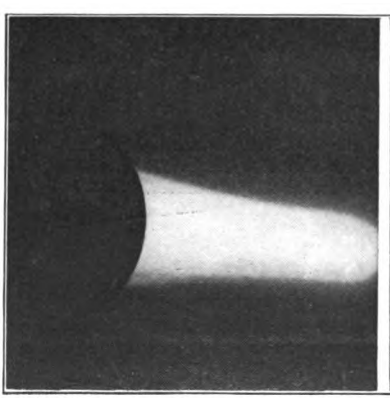

FIG. 22 — SIDE VIEW OF IMAGE SHOWN IN FIG. 21

FIG. 26—SIDE VIEW OF IMPERFECT IMAGE (SEE FIG. 25)

decreased. Continuing to move the filament farther out we repeat the images explained above, except that the rays of light that were formerly diverging now converge, Fig. 23 to 26.

Experience has shown that it is simpler to indicate the focal ad-

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justment of an automobile head-lamp by referring to a large, medium, or small image for the reason that it is difficult to determine by measurements or otherwise when the geometric center of the filament coincides with the focal point of the reflector.

The ignorance of the car owner on the subject of focusing a head-

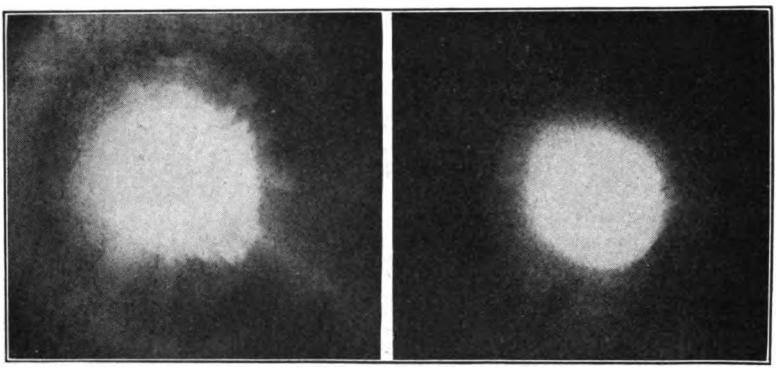
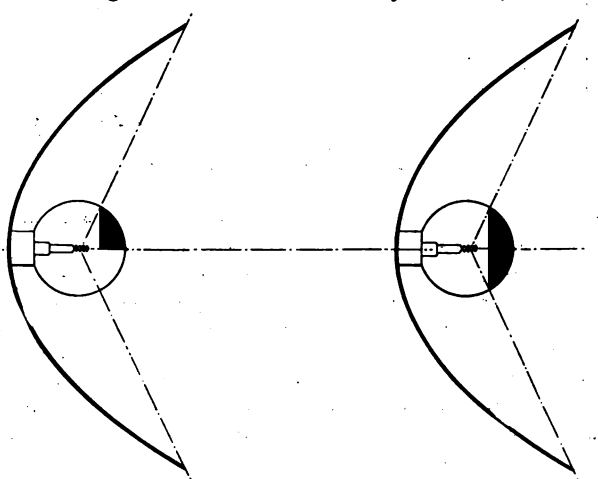


FIG. 27—BULB REFLECTION—STRAY LIGHT

FIG. 28—IMAGE WITH NO-BULB REFLECTION

lamp can be excused for the reason that few if any automobile instruction-books contain any information on the subject.

Reflected Bulb Light.—Since the distance from the center of the filament to the edge of the base is ordinarily made 13/16 in. for head-



FIGS. 29 AND 30—BULBS PAINTED TO ELIMINATE DIRECT LIGHT

lamp bulbs, and since the center of the G-16½ globe is 1 1/32 in. from the edge of the base, the center of the filament is 7/32 in. from the

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center of the bulb. It is impossible to correct this difference in the G-16½ globe for the reason that in some cases the globe itself is so close to the apex of the reflector that the focal adjustment back of the focal point is limited. In the G-16½ bulb the filament is not in the center of the globe, so that the light reflected from the globe surface strikes the reflector at an entirely different angle from that of the light of the filament. This light forms a secondary image that is impossible to control.

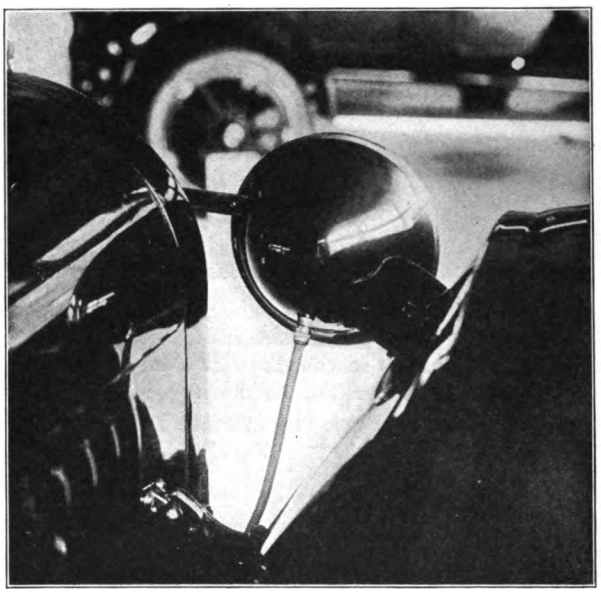

FIG. 31—IMMOVABLE HEAD-LAMP SUPPORT

Photometric tests show that this light has a value of from 5 to 8 per cent of the total light from the bulb. This becomes an important item when the beam candlepower amounts to 10,000 or over, for it then gives the reflected bulb-light a value almost equal to the light from the same lamp fitted with a frosted front glass. Figs. 27 and 28.

In the G-12 bulb (1½ in. diameter), the filament is approximately in the center of the globe so that the image of the filament reflected from the globe surface almost coincides with the filament itself. The slight difference in position makes the filament appear to be of a slightly different shape or slightly larger in area. Both the G-12 and the G-16½ bulbs cause other reflections from such parts as the tip of the globe and the bulb mount. The latter reflections, however, are not of great importance.

Direct Light is the light that comes, without being reflected, di-

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rectly from the filament. It illuminates the road and the sides of the road directly in front of the car. That portion of the direct light which rises above the axis of the lamp is practically useless and in the case of momentary glare tends to prolong the effect. Painting a portion of the globe with an opaque paint, so that the filament of the bulb in the lamp cannot be seen above the axis of the lamp, will eliminate useless direct light. Fig. 29. In the case of the spot-lamp

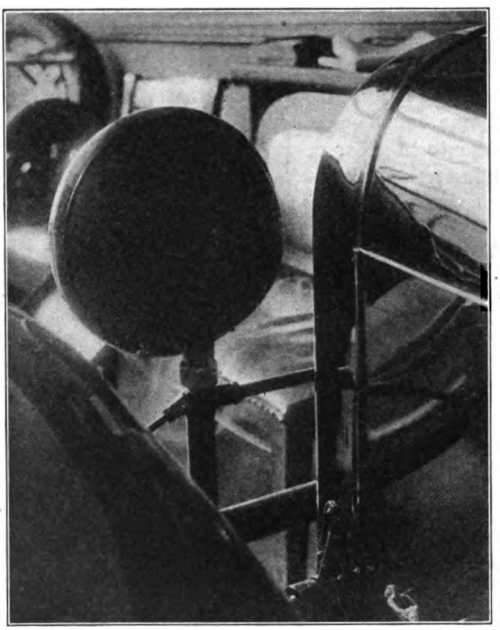

FIG. 32—IMMOVABLE HEAD-LAMP SUPPORT

all direct light should be eliminated by the painting method, Fig. 30, thus eliminating the light thrown upon the hood and mud guards of the car. This method makes it impossible to see any but the reflected light and the diffused light of the reflector, the latter being too small an item to be considered.

Radial Displacement of the Filament. The importance of proper focal adjustment has been explained, but there is one item of great importance that is generally neglected or overlooked, namely, the position of the filament with relation to the axis of the reflector. While defective sockets or socket adjustments are generally the cause of this displacement the fact must not be overlooked that the axis of the filament is not always placed in the axis of the bulb base. Well-made lamps have little or no lost motion in the sockets and bulbs as a rule have only a slight variation in the position of the filament. Cases

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are numerous, however, of defective lamp and bulb construction. Some bulbs, especially those of the Ford type, are made with the axis of the filament displaced from the base axis or it becomes so displaced from the effect of vibration, of operating at voltages above normal, or from both effects. The result of this displacement is a distorted image that unfortunately has a tendency to raise the beam of light.

AIMING OF HEAD-LAMPS

On a foggy night it is particularly noticeable that the head-lamps on cars are not properly aimed. Fully 50 per cent of the lamps are projecting the rays of light so that little of the light strikes the roadway. I believe this is due to ignorance rather than to carelessness. I have in mind one car owner who purchased fourteen different types of bulbs in order to improve road illumination, when the chief difficulty was that the lamps on his car were so aimed that hardly any of the light fell upon the road. It is only recently that proper attention

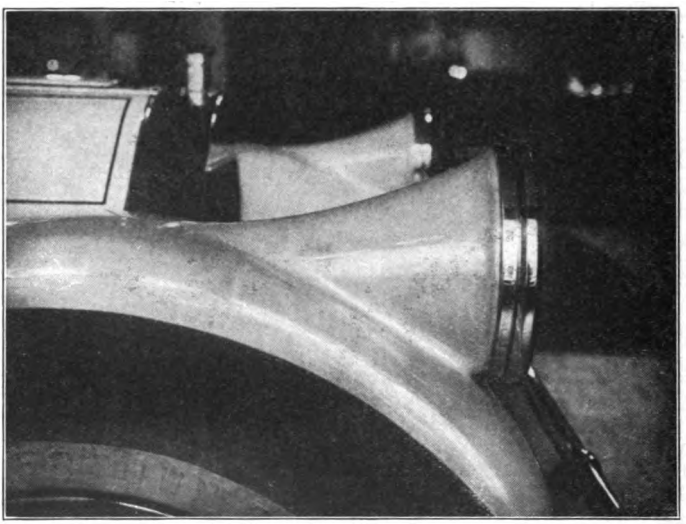

FIG. 33—IMMOVABLE ARRANGEMENT OF HEAD-LAMPS

has been paid to the aiming of the head-lamp. In the majority of cases head-lamps are aimed so that the front glasses are aligned with the rest of the car simply as a matter of appearance. In a number of cases the brackets supporting the lamps will not permit of any adjustment or alteration. Figs. 31, 32 and 33.* This often results in inefficient road illumination, and is one of the causes of glare production. It is natural for the owner of the car to assume that the lamps have been set to give maximum efficiency, but this is frequently not the

*This lamp however is said to be adjustable by tilting the reflector inside the containing case.

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case, although some manufacturers do take pains to see that the light projected is kept below the 42-in. limit.

It must be admitted that, in a majority of cases, the price and appearance govern the selection of head-lamps. Whether this is the result of ignorance or is a matter of economy I am not prepared to say.

Until the public becomes as particular about the design and construction of the head-lamps of a car as it is about the type of carbureter or ignition system employed, defective lamps will doubtless continue as standard equipment. This is a matter that can be largely controlled by the automobile buyer if he will insist upon proper construction. The manufacturer of automobile head-lamps is only too willing to turn out a lamp of proper design and construction, providing, of course, the automobile manufacturer will pay a fair price for it. But as long as the lamp manufacturer is called upon to furnish two head-lamps and one tail-lamp at a price of less than three dollars per set, we cannot expect a product that will give more than a partial control of the projected light.

If the average driver would have his car driven toward him so he could see the effect of his own lamps, there would be less blame placed upon "the other fellow" and a more concentrated effort by both to lessen the effect of glare.

SUMMARY OF CONCLUSIONS REGARDING DESIGN

Before considering in general the methods employed in glare reduction let us summarize the details of head-lamp design that should be given more careful consideration.

Reflectors should be permanently attached to supports.

Socket-Adjusting Devices. At present most socket-adjusting devices are faulty and must be made more secure. Bulb and rear adjusting devices should be discarded.

Sockets must be made to closer tolerances and must be located with their axes in the axis of the reflector.

Bulb. The G-16½ bulb should be discarded. The filament of the G-12 bulb is located near the center of and in the axis of the bulb and makes it far more satisfactory for use in head-lamps.

Correct *aiming of head-lamps* is most important.

Filament Area. Only such bulbs as have a filament area complying with the S. A. E. standard should be used.

THE GLARE PROBLEM

Agitation over the effect of glare caused by powerful head-lamps has gradually increased until we are threatened with drastic legislation. Attempts by authorities to eliminate glare completely by means of laws have, in some cases, resulted in the almost complete elimination of road illumination. In a number of cases accidents have resulted from this lack of illumination and in one or two in-

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stances the laws have not been enforced or have been declared invalid on account of this fact.

The effect of glare, which may be considered in three stages, has become a subject of vital importance. The acetylene head-lamp was universally used for road lighting until 1912, when the introduction of the electric head-lamp brought about the first serious complaint of the effect of glare. The second stage came with the shifting of the driving position from the right-hand to the left-hand side of the car. Then automobile drivers were themselves subjected to serious inconvenience, not to say danger, because they remained in the beam of reflected light thrown by the head-lamps of approaching cars for a much longer time than before. The third or culminating stage was reached with the introduction of the nitrogen or *C* type of bulb with its concentrated filament of great intrinsic brilliancy, which caused the effect of glare to be experienced not only by all drivers, but also by all users of the highway.

Glare Regulation. The problem of the regulation of glare* from automobile head-lamps will never be solved until we determine absolutely upon what basis it is to be attacked. Various laws are based upon entirely different conditions and under these conditions the glare from a head-lamp varies. Too many factors are involved in the production of glare to permit of complete analysis in this paper. One of these, however, arises from the fact that glare depends not only on the actual candlepower and intrinsic brilliancy of the source but also upon the illumination of its environment. This illumination varies from the brilliantly lighted city streets to the dark country roads, on which the effect of glare will be found at its maximum. I therefore propose that in considering automobile head-lamps from the glare standpoint all tests or comparisons be made with the head-lamp in an environment of absolute darkness.

Testing of "Non-Glare" Devices. It is regrettable that the numerous methods of conducting tests of devices for reducing the effect of glare have resulted in considerable confusion. This is the result of a lack of system in determining the conditions under which the devices are to be tested. Unless some standard form of test is devised we shall continue to read conflicting reports of the same device or method. I suggest the following methods of test: if the devices are to be tested out strictly from the automobilist's point of view then two cars, equipped with the same device and operated under identically the same conditions of bulb, voltage, candlepower, and focal position, should be used. The cars should be made to pass each other on an absolutely dark road at various speeds and the contrast between the road illumination of one car and the glare from the lamps of the other

**Back Glare.* Defractive halation, commonly known as back glare, is caused by light from the head-lamps being reflected from particles of moisture in the form of fog or rain. This halation makes it very difficult to see objects at a distance from the car which would be discernible in the daytime under the same condition of fog. This effect has little to do with the subject of glaring head-lamps although the two are sometimes confused.

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car should be the means of determining the efficiency of the method employed. The speed of the cars is a factor of no little importance. The psychological effects of passing glaring lamps at the rate of 5 and at 30 m.p.h. are entirely different.

Tests of non-glare devices are generally carried out on a country road which is frequently used by those making the test. Their knowledge of the road and the curves to be encountered aids them greatly in seeing by means of a subdued light. Should they, however, test out the same device on an absolutely unknown road the results obtained would be entirely different.

A number of advertisements of non-glare devices use photographs to show the road illumination. Unless these photographs have been made under the same conditions, namely, of atmosphere, length of exposure, size of diaphragm, speed of lens, and type of photographic plate employed, they will be useless for the purpose of comparison. It is possible to get almost any desired result upon a photographic plate with proper manipulation. For this reason I have purposely refrained from the use of photographs to show light-distribution from automobile head-lamps.

METHODS OF GLARE REDUCTION

All devices or methods for glare reduction depend either on the reduction of light or the limitation of the light zone.

The principles on which devices using the *reduction of light* method are based can be classified as (a) dimming the light; (b) change in color of light; and (c) diffusing the light.

(a) *Dimming the light* is accomplished by lowering the voltage of the circuit at the bulb, either by means of a rheostat or series connection, which reduces the candlepower of the bulb. This, however, does not alter the light distribution, so that dimming the light to the extent that at the point of maximum illumination there is no effect of glare makes a light useless for road illumination.

(b) *Change in Color of Light.* Attempts have been made to reduce glare by the change in the color of the light, but I have yet to learn of any real success with this method. Any reduction in glare by this method may be caused by the loss of light due to the absorption by the color screen or glass.

(c) *Diffusing Methods.* The diffusion of light from a source over a much larger area produces a secondary "source," the intrinsic brilliancy of which is less than that of the primary source. In the case of frosted bulbs for example the light from the small area of the filament is diffused over the surface of the bulb. The surface of the diffusing screen should be increased with any increase in the candlepower of the bulb. The effectiveness of the diffusion method therefore depends upon the candlepower of the light source and the area over which the light is diffused. Any variation in the current passing through the filament of the bulb itself changes the effectiveness of this

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method. For example, when a Ford engine runs at high speed the generator produces a voltage such as to give a light of the greatest intrinsic brilliancy. A screen that will diffuse this light properly will make the light at ordinary speeds of the engine practically useless as a road illuminant.

Facts such as these make it apparent why it is unwise, not to say unsafe, to issue a certificate of approval covering a specific type or make of glare-reducing device. For example, a screen or so-called "lens" used on a lamp with a 20-cp. bulb may diffuse enough light to reduce the glaring effect sufficiently. But if the owner changes to a bulb of higher candlepower (as he is apt to do when so much light, which should be used to illuminate the road, has been absorbed or diffused) the lamp at once becomes glaring, although the certificate protects the owner from police interference.

With the diffusion method the light distribution on the road gives a brilliant foreground with no distant illumination. The contrast between this brilliantly lighted foreground and the poorly illuminated background makes night driving at any high or even moderate speed dangerous and tiresome to the eyes.

A serious objection to the diffusion method is the fact that any reduction of glare at a distance from the car is added to the effect of glare when near the car. Supporters of this principle have suggested laws the wording of which is such as to overlook this serious defect. This adds to the confusion regarding non-glare legislation.

The principles on which devices using the *limitation of light zone* method are based can be classified as (a) cutting off light ordinarily outside of zone where light is required; (b) tilting of lamps; (c) deflection of light; and (d) modified reflectors for bulb or head-lamp.

(a) *Cutting off Portions of the Light* by means of opaque devices or of paint on the bulb, reflector, or front glass may decrease the beam candlepower 50 per cent or more. This of course is poor engineering practice. Furthermore this method is effective only when the bulb is in proper focal adjustment. For example if the upper half of the front glass is painted then the bulb must be focused to project a diverging beam. Should vibration cause the bulb to move forward sufficiently the beam will become converging, all road illumination will be lost and the unrestricted light directed upward.

(b) *Tilting the Lamps.* Without doubt the simplest and cheapest effective method of glare reduction is the tilting of the head-lamps. While the light distribution upon the road is limited in certain respects it is far more effective than obtained from any of the previous methods discussed. While it is essential that the bulb be focused properly the percentage of useful light on the road is very high with this method.

(c) *Deflection of Light.* Deflection of the light is accomplished by the use of prismatic glass fronts that tend to redirect all or a part of the reflected light. The redirection of the light in some devices

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not only keeps it within the zone in which glare is not objectionable, but also distributes it over a greater width of road. It is an advantage therefore to use a device of this character, irrespective of the existence of glare regulations.

(d) *Modified Reflectors.* Satisfactory results can be obtained by the use of a modified reflector composed of two half paraboloids, the axis of the upper one being so inclined or displaced as to throw the light toward the ground. In another form the bulb is partly surrounded by a reflector of peculiar design so arranged as to cut off the light or deflect it so that it will be thrown upon the road. Both of these devices are an advantage in that they increase the illumination of the roadway at a point where it is most desirable to have good illumination; when properly applied, they prevent the light from rising above the 42-in. limit. Care must be taken however to see that the filament is properly focused.

COMPROMISE IN SOLUTION OF GLARE PROBLEM

The confusion incident to the problem of regulating head-lamps is caused by the attempt to discover a method or means for the absolute elimination of glare without reducing to any appreciable extent the road illumination. This is practically impossible, because the ultimate solution of the problem must result in a compromise between the value of the road illumination and that of the glaring effect produced by the lamps. For instance, if the diffusion principle is adopted there cannot be sufficient illumination on the road without causing disastrous glare effects when near the car. If the deflection principle is adopted a certain amount of momentary glare due to the position of the car must be permitted in order to gain the advantage of proper road illumination, while at the same time preventing the effect of glare for probably over 85 per cent of the time the head-lamps are in use. In suggesting any means for glare reduction which may possibly be adopted in future laws, another thing must be remembered: the effectiveness of the law depends upon the manner in which it can be enforced by the average officer. Therefore simple regulations are much to be desired. The simplest method of determining glare reduction will be most effective because of the greater probability of universal enforcement.

At the same time in seeking simplicity and freedom from highly technical requirements it is unwise to allow regulations to drift into vagueness or ambiguity. The automobilist wants to know precisely the limitations of the law. While he has every intention of complying with the law he also wants the best road illumination the law will permit. A source of light of 1 cp. will cause the effect of glare if of sufficient intrinsic brightness. Therefore the specification "must not glare or dazzle" is most vague. Until we have a standard unit of glare measurement, we must not tolerate such vague requirements.

The principle of the limitation of light zone has been endorsed by

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various organizations, including the Society of Automobile Engineers. It is the most effective from the user's point of view because it reduces glare with the least loss of useful light and in most applications increases the amount of light upon the roadway. It is the method most readily covered by a simple and easily understood ordinance, an ordinance which is not only effective in accomplishing the desired result but with which it is easy to comply and which it is correspondingly easy to enforce. When once properly applied any change of voltage or candlepower of bulb (providing proper focus is maintained) does not alter its effectiveness. Bulbs of almost any candlepower can be used without altering in any way the light distribution or glare reduction.

Unlike the diffusion method there is less glaring light near the car, and this is an important item when two cars are passing on a narrow road.

Limiting the light zone will not, however, prevent glare when the car is passing over an uneven road, or over the top of a hill.

One of the greatest factors of safety in night driving is the projection of light some distance in front of the car. It acts as a warning to others approaching the highway from intersecting roads that an automobile is coming in another direction.

The projection of light at the side of the road when the automobile is making a turn is a warning to others around the turn that a car is approaching. With the diffusion method this factor of safety is eliminated.

COMPARISON OF GLARE REDUCTION METHODS

The advantages of the *Diffusion Principle* are:

1. Focusing not necessary.
2. Aiming of lamps not important.

Its disadvantages are:

1. Determination as to amount of glare most difficult.
2. Glare varies with change in voltage.
3. Glare increases when bulb of larger candlepower is used.
4. No distant illumination of road.
5. Effect of glare greatest near car.
6. No warning beam in advance of car.

The advantages of the *Limitation of Light Zone Principle* are:

1. No expense to tilt lamps.
2. Distant road illumination excellent.
3. No glare whatever near car.
4. Most efficient light distribution on road.
5. Simple method of determining compliance with reasonable ordinance.
6. Temporary changes in voltage or in candlepower of bulb do not cause change in glare, providing bulb is properly focused. Practically no limit to amount of light that can be used safely so long as it is kept below 42-in. limit.

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7. Warning beam can be seen many feet in advance of car, and helps to reduce contrast between approaching head-lamps and roadway.
8. Height of a beam of light can be absolutely determined in daytime by looking into lamps from point ahead of car and so adjusting them that reflected light does not strike eye when latter is more than 42 in. above ground.

Its advantages are:

1. Exact focusing necessary.
2. Causes momentary glare when car is passing over top of hill, or extremely rough or uneven roads.

AUTHOR'S CONCLUSIONS

No mention has been made of any devices designed to reduce or eliminate glare, for we must first decide after a thorough discussion which principle of glare reduction will be most effective. With that problem solved, we can then consider the various methods based upon the approved principle and later on the devices themselves. I do not mean to infer that there are not on the market to-day effective devices for glare reduction, but I prefer that the subject be discussed with due regard to the order of importance of its respective phases.

We must first select the best principle upon the basis of which the design is to be carried out; we must then select the most efficient method of applying this principle; and we must finally see that the method is such that an ordinance can be framed to render it effective. The last requirement means that the simplest form of test must be applicable so that there can be no question regarding its enforcement by officers of average intelligence.

While there are but two principles to be discussed there are almost four million automobile car owners awaiting some definite information regarding the reduction of glare.

If the consensus of opinions expressed in the discussion of this paper favor one principle over the other the author feels that its purpose has been accomplished.

DISCUSSION

H. W. SLAUSON:—What quality of road illumination is it that causes unevenness in the road, holes or shadows, to stand out more prominently with one type of lamp than with others? It seems that one type will cause a shadow or maximize the effect of holes or shadows in the road, while another will give an appearance more similar to daytime illumination.

PROF. F. R. HUTTON:—The kernel of Mr. McMurtry's paper is his expression of the need of a unit of illumination. I suggest that Mr. McMurtry use a screen having some surface that he has yet to create and that gives an effective 100-per-cent reflection; and that from this we shall photometrically determine what is the amount of candle-power return from a square foot of the thus-illuminated area.

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Courtesy of New York Edison Co.

FIG. 34 (UPPER)—DETAILS WITH PRACTICALLY NO LIGHT. FIG. 35 (LOWER)—LIGHT ONLY FROM HEAD-LAMPS

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I ran into a singular experience down on the shore some time since, where a head-lamp illuminating a certain area gave full warning of the approach of the car to the horse-driver starting a dark horse out of a side-lane; but this illumination did not make the horse —a bay—visible to the car-driver. The tangle of the legal discussion as to responsibility for a subsequent collision centered on the distinction, which the lawyer refused to let me make, between visibility and illumination. We can determine how many candlepowers strike a given area; this is illumination. But it is quite different from visibility, which introduces the human factor, the condition of the retina of the eye to receive impressions of objects. The thing that may be well illuminated may have a low visibility. If the eye is blinded, if the nerves in its center can no longer take cognizance and the lens-muscles no longer control illumination, visibility has disappeared and a person is, as it were, blind. Glare is the excessive illumination per square foot of illuminated surface that the nerve centers in the back of the eye, or the retina, refuse. Below that the eye says, "All right. I can see perfectly well." Above that the sense of vision is not carried back to the brain.

W. F. LITTLE:—Mr. McMurtry has dealt with three types of head-lamps; those which: (1) Concentrate the beam; (2) Deflect the beam below the horizontal; and (3) Diffuse the beam.

Those who favor the first method desire the smallest possible beam, believing that the direct light from the lamp will take care of the illumination near the car and a sufficient spread will be had for the distant points. The concentrated beam makes visible objects within this beam, and renders invisible objects without, by reason of contrast between the brightly and dimly-lighted areas. Also, as the eye is adapted to the more brightly-lighted areas, it has greater difficulty in discernment in the less bright areas. Those believing in the deflection of light type usually desire a more or less fan-shaped beam below the horizontal, producing illumination back to the car. The deflection of the beam below the horizontal makes the objects within the beam visible to a lesser extent because of its lesser intensity. It does to a certain extent render surrounding objects visible. In order to illuminate the surroundings, the sacrifice of the beam must be great, as the total amount of light is spread over a large area. This type of head-lamp also renders invisible practically all objects above the horizontal; therefore only such portions of vehicles and pedestrians are seen as are below the axes of the lamps. Those believing in the diffusion of beam type desire a general spread of illumination, both above and below the horizontal.

The diffusion type of head-lamp renders distant objects even less visible, because of the still greater sacrifice of the beam intensity.

Obviously the vision of prime importance lies in a restricted area in front of the car, and this area is usually covered even by the most concentrated beam. The discernment of the surroundings, while of

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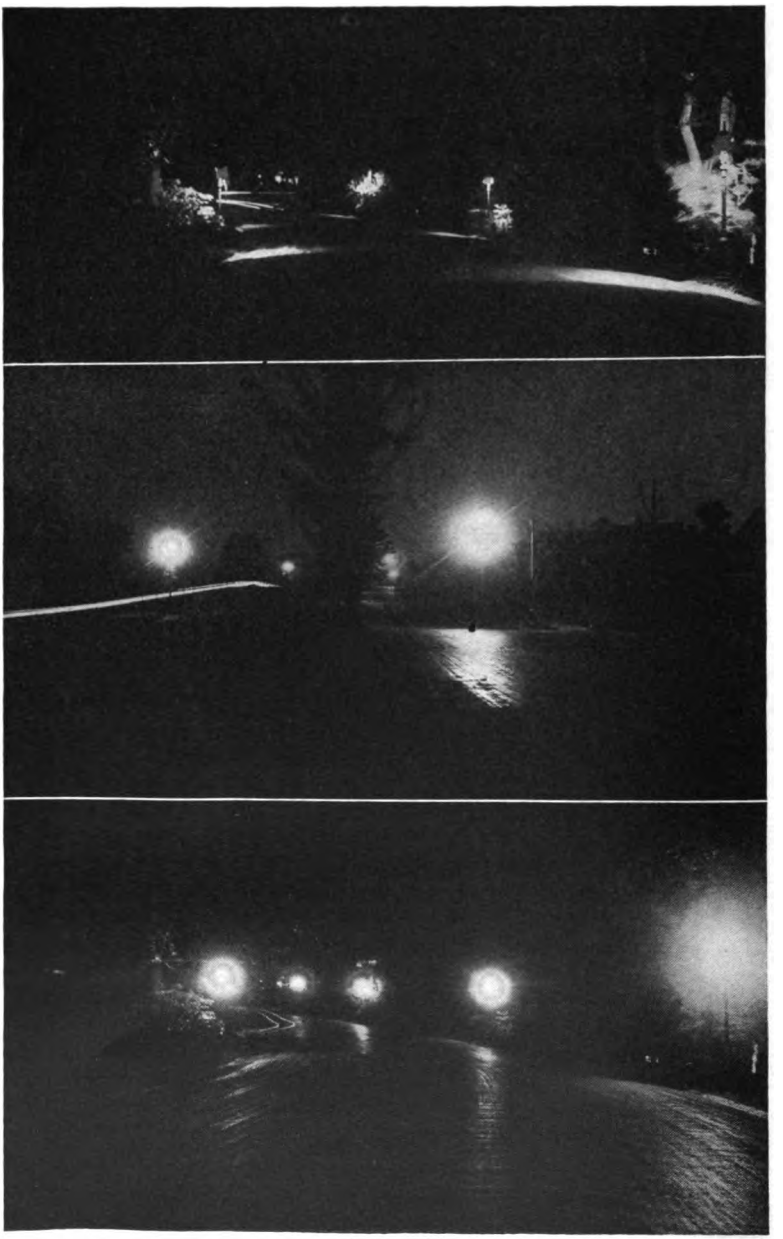

FIG. 36 (MIDDLE)—STREET SURFACE ARTIFICIALLY ILLUMINATED. FIG. 37 (UPPER)—LIGHT KEPT BELOW 65 DEG. ANGLE. FIG. 38 (LOWER)—LIGHTING WITH UNSHADED LAMPS

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secondary consideration, is important. Is not therefore a proper balance of these three systems the best solution?

Night vision is almost entirely contrast or silhouette vision, and we see by the same process for all three types of lighting. Even in daytime objects are frequently seen by contrast rather than by the light that falls upon them. Out-of-door night vision of artificially-illuminated objects is somewhat similar to twilight vision; all objects appear in various tones of gray, ranging from white to black, and color is seldom in evidence; therefore, sharp shadows and contrasts are necessary for clear vision.

Fig. 34 shows the extreme details that are discernible with practically no light upon the object. If lighted only by head-lamps the reverse of this picture, Fig 35, would be seen.

Fig. 36 shows the appearance of the street surface when artificially illuminated. In the one case the surface is glossy, showing high specular reflection; in the other it is mat, showing no reflection. Light from a head-lamp falling upon the glossy surface would be reflected upward, and the head-lamp would be far less effective for illuminating purposes than if it should be directed upon the mat surface, where the detail and shadow would be apparent. This answers a question previously asked as to why head-lamps appear more effective on some streets than on others.

Figs. 37 and 38 show the importance of directional lighting. In Fig. 37 all the street lamps are shaded so that no light is emitted at an angle higher than 65 deg. The actual illumination on the street surface in this case is greater than in Fig. 38, but the specular reflection is killed by the obscuration of distant lamps, and the detail of the surface disappears.

Another feature of projector lighting that should not be lost sight of is the difference in level between the driver and the head-lamps. Should the head-lamps be placed on the level with the driver's eye, practically all shadows would disappear, and a rough road would probably appear smooth and level. This difference in level should not be sufficient to exaggerate the unevenness of the road-bed. The driver soon learns the extent to which the road-bed is irregular by the length of the shadows.

H. P. GAGE:—It is first necessary to consider the kind of road that is to be illuminated. There are in general three distinct types of road. One the country road, which is little traveled, the only problem is to illuminate the road; a low intensity will answer, and it is not necessary to worry about glare, because the road is not much traveled. The second type of road is the much traveled macadamized or state road. Here many automobiles are operated on summer evenings, and therefore glare is a most serious obstacle. The third type of road is found in cities, where it is not necessary for the driver to carry his own light; the light is furnished by street lamps. Therefore it is only necessary to carry marker lamps, so that other people can see the

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vehicle. It is the second type of road on which the great problem of head-lamp illumination is encountered.

A laboratory study of the head-lamp will not reveal what it will do when placed on the front of an automobile and used, unless we take some means of bringing the road into the laboratory. To do this I have taken a number of photographs of roads under carefully arranged conditions. (Slides of these were shown.) The camera with an objective of 11 in. equivalent focus was used in this and another set of photographs to be described later. The camera was set at a height of 42 in. above the road. A steel tape was used to measure a definite distance from the camera, such as 50 or 100 ft. A rule at a distance of 50 ft. from the camera was held vertically so as to measure a height of 42 in. above the road. By thus locating a point 42 in. above the road and 50 ft. directly down its axis, we have a concrete picture to work to, and we can draw an outline of just what parts of the roadway we wish to illuminate, or by means of photographs of projected light patterns, we can predict how the road will be illuminated by those light patterns. Referring to one of these road pictures; I would like to illuminate the part of the road straight ahead of the car, just under the 42-in. height as brightly as possible, so that I can have the best view possible of distant objects. I would also like to have a spreading light to illuminate the whole width of the road and the ditches. If I comply with the law I must not have a bright light above the 42-in. level, so that I will not cause a disagreeable glare to anyone approaching.

The set of photographs to go with the road pictures was taken with the same camera and objective. The lens of the camera was placed even with the front of the head-lamp. The head-lamp projected its light pattern on a white screen. This screen was covered with reference lines, a heavy horizontal black line to represent the 42-in. height and a heavy vertical line to represent the center of the road in front of the car. Photographs taken under these conditions will be on the same scale as the road pictures and can be directly compared. The most convenient method of showing this comparison is to paste together the lantern slides of the road and the screen image, taking pains that the crossing of the heavy axis lines shall fall directly over the 42-in. level on the road picture. Those parts of the road that would be illuminated by the particular head-lamp used can then be seen. If all of the light is kept below the 42-in. level, the best driving light is obtained when the highest intensity falls just below the 42-in. line, when there is a good horizontal spread to illuminate fences and ditches, and when none of the projected light falls at a shorter distance than from about 30 to 40 ft. in front of the car.

A photograph I have taken at night from the driver's position shows that with a certain lighting device none of the projected light beam rises above the 42-in. level, and that the side spread gives a good road illumination. There is some light above the 42-in. level,

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which comes directly from the bulb, and which has not been reflected from the parabolic reflector. This light, although not very bright, is sufficient to keep the driver from being brushed out of the car by overhanging tree limbs.

This photograph also illustrates one of the points brought out in the discussion; namely, the effect that would obtain if the head-lamps were set at a different height. A hump in the road is revealed by the dark shadow behind it. If this head-lamp were mounted at the height of the driver's eye, there would be no shadow cast. If there were, the driver could not see it, so that there would be danger of getting thrown out of the car by a hump that is rendered easily visible when the head-lamps are located at a height above the ground equal to about half that of the driver's eye.

The question of how much light above the horizontal can be allowed can be studied by setting up a group of illuminated letters near a head-lamp. When looking directly into the lighted head-lamp these letters cannot be seen on account of the glare effect, but if a suitable anti-glare device is used, the letters can again be seen. From rough experiments of this nature I would conclude that if I can provide a reasonable road illumination myself, and the car I meet does not project a beam of light of higher intensity than 1000 cp., I can pass without any difficulty, but if the other car hits me with the full head-lamp beam of from 20,000 to 60,000 cp., I will have a hard time to pass it.

E. H. Bostock:—Glare is the superabundance of light upon any given area beyond that the eye can use. Undoubtedly some day we shall have a unit of glare, based on the average of a number of observations, that will fill the legal definition, perhaps, of what glare is. As far as I am concerned, the only way that we can decrease the dangerous glare from automobile lamps is by distributing the beam candlepower of any head-lamp over a larger area, so that its brilliancy at any known point is decreased within the reach of my eyesight and therefore is not glaring to me.

At present the illuminated area is simply that of the surface area of the parabola of the head-lamp we are facing. If we can increase that area without sacrificing any appreciable amount of light, we have some effect upon glare. It seems to me there is just one point upon which we can work and that is by increasing the surface area of the front glass of the head-lamp, which is being done by some manufacturers of front glasses. The problem will probably be solved when some one produces a cover or front glass whose inner surface is made in such fashion that it presents absolutely the maximum reflecting surface over which the light is spread and lowers the candlepower upon any one point.

The glass would have its inner surface covered with contiguous covers or prisms of such height and base that the maximum amount

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of surface is presented to the beam and shaped so that intense reflection between their surfaces is established.

I speak of the inner surface particularly; if we use the outer surface of the glass, we do not increase the area because the departing beam cannot have its area increased beyond that of the plane it is leaving.

DEFLECTION OF LIGHT METHOD BEST

W. E. McKechnie:—I agree with Mr. McMurtry that glare is better prevented by the deflection of light than in any other manner, as far as we have gone. Two or three different devices have been brought out recently that do allow of some permissible light above the horizontal; that is, light that does not come in such a way that it has a blinding effect upon the approaching driver.

After we have classified these different non-glare devices, it may be possible to recommend some different classes that can be utilized to good advantage on cars already being driven on the road. Then we can continue standardizing head-lamp apparatus and have reflectors constructed of sufficient accuracy so that we can control more definitely the projected beams of light. That would apply, of course, to the future manufacture of the lamps and not to the bulk of lamps on cars being driven to-day.

Wm. Churchill:—At present we must be sure that the head-lamp is accurately designed and built, and that there must be means for accurate adjustment. Reference was made in the paper to the granting of service certificates of approval to devices, which, however correct in themselves, with incorrect adjustment are far from satisfactory. I believe that it is of much importance to manufacturers, and even more to the general public to provide for a definite approval. The situation in Massachusetts during the past year has been much confused because no approval was arranged for. An ordinance or provision was put into effect there by the Highway Commission and no one knows whether his device conforms to the law until it is approved by some country justice.

We ought to have some form of approval, but not such as to insure freedom from arrest unless it is clear that the device is properly installed. The mere fact that a device may be a good thing when properly utilized certainly should not guarantee one against being called to account if his bulbs are not properly focused or if for any other reason his head-lamps are not efficient.

If we are going to settle this problem satisfactorily, we must decide what sort of distribution of illumination is ideal, what distribution of light we want in order to be able to see most effectively, recognizing, of course, that we cannot be permitted to distribute the beam in any way that will interfere seriously with the vision of other users of the highway.

I use an offhand definition of glare—I have not been able to dis-

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cover any scientific definition—by saying that a lamp produces glare when the illumination is of sufficiently high intrinsic brilliancy to interfere with the vision of objects in its immediate vicinity. I believe it is entirely possible to construct apparatus and develop a method that will give us an accurate scientific standard of glare.

AUTHOR'S CLOSURE

ALDEN L. MCMURTRY:—The lower the lamps are below the line of vision the more pronounced will be the shadows caused by depressions or the obstacles in the road. If the lamps are above the line of vision there will be no shadows at all to speak of. I drove behind a car with the lamps mounted extremely high, and it was almost impossible to see the uneven part of the road in time to slow up for it.

I have not made any experiments in illumination of the background of the car, that is, illumination back of the automobile lamps of the car. I do find, however, that with two cars facing each other, with the lamps arranged identically the same, the illumination of the road all around the lamps will enable one to see every point at the side of the other car.

In regard to the increases of area of the lamps I might say that if any legislation is to be enacted it will affect all the lamps that are on the cars to-day. We must find some means of taking care of those lamps first before we consider how the new lamps should be made.

I know of one instance where the engineering department was considering two or three different lamps, that is, which lamps they were to approve, while the salesman of one of the lamp manufacturers was on his way home from Detroit with an order from the purchasing department. So long as things like that happen we will get good lamps.

I want to emphasize that if the public knew how properly to focus and aim the lamp, in other words, how to get the best results from the present-day type of lamp, it would reduce the effect of glare by over 50 per cent. Then there would be no need of any laws. It is simply a matter of ignorance on the part of the car owners. I have heard on numerous occasions that most of the glare was caused by Ford lamps. That may be true to a certain extent on account of the high voltage from the flywheel generator. But considering its construction, the Ford lamp is far better than 50 per cent of the lamps used on the expensive cars to-day.

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GENERAL INDEX

PAGE

Aeronautic Division, First Report of..... 1
Acceleration, six and eight-cylinder cars (curves).....263, 264, 272
tests, method of conducting.....262
Accessibility, automobile engine.....244
Adhesion, coefficient of, for solid rubber tires.....366
AERIAL NAVIGATION OVER WATER. ELMER A. SPERRY.....153
Aerial navigation, rules for.....162
Aerofoils, sections of variable forms..... 51
AERONAUTIC METAL PARTS, STANDARDIZATION OF. F. G. DIFFIN..166
Aircraft engines, comparison of high- and low-pressure types.....181
design to secure light weight.....180
volumetric efficiency of 186
weights of 185
AIRPLANE CONSTRUCTION, SOME PROBLEMS IN. CAPT. V. E. CLARK, CAPT. T. F. DODD AND O. E. STRAHLMANN..... 40
AIRPLANE WING-TRUSSING, THE EVOLUTION OF. F. W. PAWLOWSKI.207
Airplane design, improvements suggested in..... 61
reconnaissance-type, performance (curves)..... 54
AIRPLANES, SUGGESTIONS FOR STANDARD TESTS OF. JNO. J. ROONEY.194
Airplanes, accuracy in manufacturing.....194, 202
economical speeds of, with fixed and variable blade propellers (curves) 55
metal construction for 48
military functions of 41
performance of, with fixed and variable camber wings (curves) 52, 53
pursuit 42
reconnaissance 42
side-bracing 213
examples of 215
special types 217
AKIMOFF, N. W. REMARKS ON DYNAMICS OF THE AUTOMOBILE...141
Appearance, factor in automobile design.....239
Applications Approved 36
Attendance at Council Meetings..... 37
AUTOMOBILE SHOWS, YEAR'S PROGRESS AS OBSERVED AT. J. EDWARD SCHIPPER 239
Automobile, engineering, status of 83
modes of vibration of 147
bodies, space proportions in.....248, 256
AVIATION ENGINES, SOME NOTES ON HIGH-PRESSURE. LEIGH M. GRIFFITH 180
Axles, types on new models 246

Balance, conditions of complete running 120
reason for, in automobiles 113, 239
running, of body 114
BALANCING OF ROTATING PARTS, DYNAMIC. F. HYMANS.....113
Balancing machines, Akimoff type (ill) 129
cone (ill) 119
floating bearing (ill) 121

NOTE: Titles of papers are given in capital letters.

Digitized by Google

PAGE

Balancing machines, function of 124
function of 124
Norton type (ill) 126
operation of 120, 128
principal types 113
Bearings, power loss in front-wheel 379, 383
BERRY, O. C. A STANDARD OF CARBURETER PERFORMANCE.....312
Biplane wings, side-bracing of 213
forces in 215
Biplanes, suggested construction of 217
Boilers, steam-car 221
working pressure of steam-car 228
Bolts, advantages of vanadium-alloy steel 173
design of, for aeronautic use 169
uniform strength 178
variety of hex, for aeronautic use 170
Brakes, airplane, landing gear 49
conduction of heat from 370
design of, for mountainous districts 369
diagonal 374
electric 370
four-wheel 367
front-wheel 374
hydraulically operated 369
improvement in design of 246
legal requirements for 376
legislative action regarding 371
materials for 376
motor truck 374
mounted at rear of transmission 371
pumping system to absorb energy from 372
radiating surface required for 371
vacuum 255, 257, 370
Braking, light required in 305
Brilliancy, effect of intrinsic 304
Bulbs, focusing head-lamp 396
Bushings, fiber, for spring eyes 286
lubrication of 286
use of rubber 291
Business Session of Society's Meetings..... 28
Camshafts, overhead drive, for airplane engines.....192
Cantilever springs, advantage of 148
CARBURETER PERFORMANCE, A STANDARD OF. O. C. BERRY.....312
Carbureters, adjustment of 318
altitude adjustment for airplane-engine 50
functions of 312
location on airplane-engines 62
Carburetion, proper mixtures for 313
tests to determine best 315
CHILTON, ROWLAND. CHASSIS LUBRICATION.....280
CLARK, CAPT. V. E. SOME PROBLEMS IN AIRPLANE CONSTRUCTION. 40
Clutches, adjustment of 245
Combustion chambers, automobile engine 244, 254
farm-tractor engine 70
design 363
Comfort, factor in riding.....239, 254
COMMERCIAL MEN AND ENGINEERS. CHAS. W. MEARS.....232
Compasses, limitations of magnetic 153
Compression-ratio, high-speed engine 105

Digitized by Google

PAGE

Connecting-rods, high-speed engine 107
Constitutional amendments, discussion of..... 30
Contour lines, use of, to represent engine performance.....344
Controls, standardization of airplane 176
Cooling-air, heat lost to 88
measuring 94
systems, airplane-engine 63
water, heat lost to 88, 89
temperature, control of 242
Copper for brake radiating surfaces 372
Cord tires, rolling resistance of 378, 382
Council meeting attendance 37
Council members.....420
Crankcases, airplane-engine 61
distortion 253
Crankshafts, bending moments 116
counterbalanced (ill) 115, 116
distortion 253
high-speed engine 108
Cycles, farm-tractor engine 68
Cylinders, aircraft-engine 182
farm-tractor engine 68
heads, detachable 241, 253
relation of bore to speed and mean effective pressure (curves) 69
steel, for aircraft engines 188, 192, 193

DIFFIN, F. G. STANDARDIZATION OF METAL PARTS FOR AERONAUTIC USE 166
Distillation test, gasoline 360
DOBLE, ABNER. STEAM MOTOR-VEHICLES 220
Drift, correction for 154
set, synchronized 158
DYNAMICS OF THE AUTOMOBILE, REMARKS ON. N. W. AKIMOFF...141

Efficiency, fuel mixtures for maximum 320
mechanical, of engine at various loads 90
methods of increasing engine 84
volumetric 240
Electric Equipment Division, Eighth Report of..... 7
Electric Vehicle Division, Fifth Report of 8
Energy absorbed in braking 368
Engineers, methods of thinking 232
work of, with commercial men.....238
ENGINES, ESSENTIAL FEATURES OF HIGH-SPEED. A. F. MILBRATH.104
HEAT-BALANCE TESTS OF AUTOMOBILE. WALTER T. FISHLEIGH AND W. M. LAY..... 82
TESTING VARIABLE-SPEED, BY A NEW METHOD. DANIEL ROESCH 338
Engine, design as affected by grade of fuel.....355
farm-tractor, specifications 67
high-speed, design 104
lubrication 109
performance 262
internal combustion, possibilities for development 97
operation, difficulties in..... 96
performance, with different fuel mixtures 316
sixteen-valve four-cylinder 240, 252, 256

Digitized by Google

PAGE

Engine, testing forms 10-11
rules and directions for 12
uniflow, for steam cars (ill.).....225
V-type, field of 243
Wisconsin, characteristics (curves) 110
Engine and Transmission Division, First Report of..... 9
Exhaust gas analysis, six-cylinder engine (tab.)..... 92
heat lost to 89

Fabric tires, rolling resistance of 378, 382
Farm-tractors, factors influencing use 66
phases of development 65
Filaments, head-lamp bulb 394
examples of 396
Fire protective devices, airplane 50
FISHLEIGH, WALTER T. HEAT-BALANCE TESTS OF AUTOMOBILE ENGINES 82
METHODS OF COMPARING AUTOMOBILE PERFORMANCE 258
Flight, precautions in, over water 162
Formulas, performance and ability 265, 269, 270, 273
Friction horsepowers, six-cylinder engine (tab.)..... 92
Front-driven automobiles 250
Fuel, automobile, changes in 347
consumption, measuring 93
of engine, at various loads 90
Detroit, ordinance 253
economy, four and eight-cylinder cars (curves)..265, 266, 273
low-grade, use of 242
properties of 348, 354
use of heavier 356, 360
FUEL QUESTION, FROM DRIVER'S VIEWPOINT. F. C. MOCK.....355

Gages, gasoline supply, for airplanes 50
composition of different 350
Gasoline, consumption, six-cylinder engine (tab.)..... 92
supply system for military seaplanes (ill.) 46
standardization of 359
Gearboxes, on new models 245
Gearshift, level-handle, positions of..... 25
positions for four-speed truck 26
GLARE, HEAD-LAMP—WHAT IS IT? J. B. REPLOGLE.....297
Glare, definition of 300, 304
effect of 406
elimination of 301
factors involved in 309
meter, inexpensive form of (ill.).....303
reducing devices, legal approval of 418
methods of 407, 419
terminology for parts of head-lamp 395
types of head-lamp 392
Greases, advantages of, for chassis lubrication 292
compared with oil, as lubricants 286, 287, 289
GRIFFITH, LEIGH M. SOME NOTES ON HIGH-PRESSURE AVIATION ENGINES 180
HEAD-LAMP DESIGN, ITS EFFECT UPON GLARE REDUCTION. ALDEN L. MCMURTRY 387
HEAD-LAMP GLARE—WHAT IS IT? J. B. REPLOGLE.....297

Digitized by Google

PAGE

Head-lamps, aiming 404
glasses, construction for best lighting 418
function of parts 387
names of parts 388
results of adjusting 306
socket adjustment 389
suggested law regulating intensity of 310
reflector supports 388
HEAT-BALANCE TESTS OF AUTOMOBILE ENGINES. WALTER T. FISHLEIGH AND W. E. LAY..... 82
Heat-balance data for automobile engine (curves).....83, 88
distribution, six-cylinder engine 341
HORNING, H. L. ULTIMATE TYPE OF TRACTOR ENGINE..... 65
Horsepower, farm-tractor engine 67
fuel mixtures for maximum.....320
heat consumed as brake 87
variation in engine 276
Huff, Presidential Address of Russell..... 28
HYMANS, F. DYNAMIC BALANCING OF ROTATING PARTS.....113

Inertia forces, high-speed engine 108
improvements in 247
Illumination, of street surfaces 415
laboratory study of 416
contrasted with visibility 411
Illuminometers, types of 303
Inertia forces, high-speed engine.....108
Inflation pressures, effect of tire, on riding qualities 386
rolling resistance 381
Instruments, airplane test 196
Iron and Steel Division, Tenth Report of 17

Kerosene, farm-tractor engines, use of 72
ignition of, in starting steam-cars 225

Landing gear, airplane folding 49
Leather, automobile upholstery 250
Lift-trusses, advantages of single, for biplanes 214
Light, effect of, on human eye 299, 304
relative intensity of 301
Lighting ordinance, Baltimore 298
Load distribution on vehicle wheels 368
LOCKWOOD, E. H . POWER LOSSES IN PNEUMATIC TIRES.....377
LUBRICATION, CHASSIS. ROLAND CHILTON.....280
Lubrication, high-speed engine 109
necessity for chassis 255
pressure-feed systems 243, 256
Lubricating oil, delivery of, to chassis parts 283, 290
systems, Fergus 283
cross-section views of (ill.) 294
Lubricants, use of exhaust-heat to thin 289

Machine guns, method of firing, on airplanes 50
screws, standardization of 176
MCMURTRY, ALDEN L. HEAD-LAMP GLARE AND ITS EFFECT UPON GLARE REDUCTION 387
Magnetos, methods of mounting on airplanes 62
Manifolds, effect of, on engine operation 242, 318
heated intake 252

Digitized by Google

PAGE

MEARS, CHAS. W. THE GAP BETWEEN COMMERCIAL MEN AND ENGINEERS 232
MILBRATH, A. F. SOME ESSENTIAL FEATURES OF HIGH-SPEED ENGINES 104
Miscellaneous Division, Ninth Report of 17
MOCK, F. C. THE FUEL QUESTION, FROM THE DRIVER'S VIEW-POINT 347
Mufflers, requirements for airplane engine 49

NELSON, A. L. OVERHEAD VALVE PROBLEM OF AN ALUMINUM ENGINE 328

Officers, election of 36
Officers of the Society 420
Oiling systems, airplane-engine 61
Ordinances, anti-glare 297

PAWLOWSKI, F. W. THE EVOLUTION OF AIRPLANE WING-TRUSSING 207
Pedals, position of control 25, 251
PERFORMANCE, METHODS OF COMPARING AUTOMOBILE. WALTER T. FISHLEIGH 258
Performance, airplane 194, 203
characteristics, six-cylinder engines (curves), 89, 338, 340
factors in automobile 239, 258
farm-tractor engine record 70
formula 260
high-speed engine 110
Pins, rod and yoke-end, variety of....166
Pistons, aircraft-engine 184
aluminum, clearances 242, 253, 255
high-speed engine 107
Powerplants, steam-car 222
Pressures, mean effective, results of 240
Presidential Address of Russell Huff 28
Propellers, airplane, with variable pitch-angle.... 53
stresses, airplane, variations during flight.... 57
relation of efficiency and effective pitch (curves).... 57
systems, airplane 43
methods of installation.... 44

Radiators, airplane-engine, with adjustment of amount of cooling .50
oil for cooling 295
steam-car 221
Rebound clips, spacers and bolts 18
Reflectors, head-lamp 307, 388
REPLOGLE, J. B. HEAD-LAMP GLARE—WHAT IS IT?....297
RETARDATION OF THE AUTOMOBILE. JOHN YOUNGER....365
Retardation, objects of 365
value of, at various speeds 366
ROESCH, DANIEL. TESTING VARIABLE-SPEED ENGINES BY A NEW METHOD 338
Rolling resistances, distribution of 379
measured at circumference of 32 by 4-in. tires (curves) 378
obtaining 377
six-cylinder car 383
ROONEY, JNO. J. SUGGESTIONS FOR STANDARD TESTS OF AIRPLANES.194

Digitized by Google

PAGE

Rotating body, definition of ideal 114

SCHIPPER, J. EDWARD. ANALYSIS OF YEAR'S PROGRESS AS OBSERVED AT AUTOMOBILE SHOWS 239
Sections of the Society 421
Shock absorbers, for airplane landing gear..... 49
objection to frictional 144
Socket adjustment, head-lamp 389
Spark-plugs, effect of mixture in depositing soot on.....320
insulators, porcelain 190
quartz 189, 193
metric 2
terminal-threads 184
Specification forms, airplane 196
airplane-engine 199
airplane-propeller 200
SPERRY, ELMER A. AERIAL NAVIGATION OVER WATER.....153
Storage battery, dimensions of 8, 9
Springs, behavior of, as shock-transmitting elements 144
cantilever, dimensions of 20
damped oscillation of 142
friction in 142
shackles, lubrication of.....286, 289
trimmed end 19
Springs Division, Sixth Report 18
STANDARDIZATION OF METAL PARTS FOR AERONAUTIC USE. F. G. DIFFIN 166
Starting motors, airplane-engine..... 45
STEAM MOTOR-VEHICLES. ABNER DOBLE 220
Steam-cars, brakes on 231
characteristics of 227
disadvantages of early 221
efficiency of 227
production costs 231
starting 224
Steam generator, new type (ill.).....223
powerplants, advantages 227
Stresses, compared in automobile and aircraft engines.....177
Stroke-bore ratio, high-speed engine 104
Suspensions, new ideas on 255
on new models 246
automobile, conclusions based on formula for pitching periods 148
vibration of elemental one-wheel 146

Tail-lamp, dimensions of 7
Tanks, airplane fuel 46
Tappets, adjustment of valve 337
Temperatures, determining cooling-water 94
measuring exhaust-gas 95
TESTING VARIABLE-SPEED ENGINE BY A NEW METHOD. DANIEL ROESCH 338
Testing Laboratory at Purdue University (ill.).....313
University of Michigan (ill.)..... 94
Test forms, airplane 195, 196
results, six-cylinder engine (tab.)..... 91
Tests, airplane engine 203
data taken in engine 339

Digitized by Google

PAGE

Tests, six-cylinder engine, procedure 93
valve, high-speed engine 106
TIRES, POWER LOSSES IN PNEUMATIC. E. H. LOCKWOOD 377
Tire and Rim Division, Tenth Report of 20
Tires, pneumatic, heat dissipated in resistance by 381
suction of 385
temperatures in 386
Torques, horsepower and fuel consumption at constant (curves) . 343
TRACTOR ENGINE, ULTIMATE TYPE OF. H. L. HORNING 65
Treasurer's Report 38
Truck, gearshift, position of 26
Standards Division, First Report of 25
Trusses, use of bridge, for biplanes 208
wireless, for aircraft 210
examples of (ill.) 211
Tubing, airplane fuel-lead 110, 111

Universal-joints, lubrication of 285, 293

Vacuum tanks 250, 255
Valve gear, aircraft engine 187
Valves, aircraft engine 185, 187
dimensions 16
exhaust, use of twin 252, 256
high-speed engine 105
overhead 241, 243, 256
variety of sizes 177
VALVE PROBLEM, OVERHEAD, OF ALUMINUM ENGINE. A. L. NELSON . 328
Vapor tension, gasoline 353
Vibrations, complex, of rotating bodies 126
material needed for absorbing 50
reducing, in airplanes 45

Wave crests, determining velocity of, for aerial navigation 164
Wear, causes of chassis 280
Weight, decrease of, in aircraft design 171
effect of distribution of, on riding qualities 148
reduction of automobile 241
Wheelbase, proper length of, for best riding qualities 148
effect of, on riding qualities 149
Wind resistance, automobile 366
Wing fittings, standardization of airplane 175
Wing-trussing, biplane 208
examples of (ill.) 209, 211
monoplane 207
need for new types 217
Wings, airplane, advantages of variable-camber 214
Wisconsin engine, characteristics of (curves) 110

YOUNGER, JOHN. RETARDATION OF THE AUTOMOBILE 365

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